

Mechanick-Powers:
OR, THE
M I S T E R Y
O F
NATURE and ART
UNVAIL'D.

Shewing what *Great Things* may be perform'd by
Mechanick Engines, in removing and raising Bodies
of vast Weights with little strength, & force; and
also the making of Machines, or Engines, for raising
of Water, draining of Grounds, and several other
Uses.

TOGETHER

With a Treatise of *Circular Motion* artificially fitted to Mecha-
nick use, and the making of Clock-work, and other Engines.

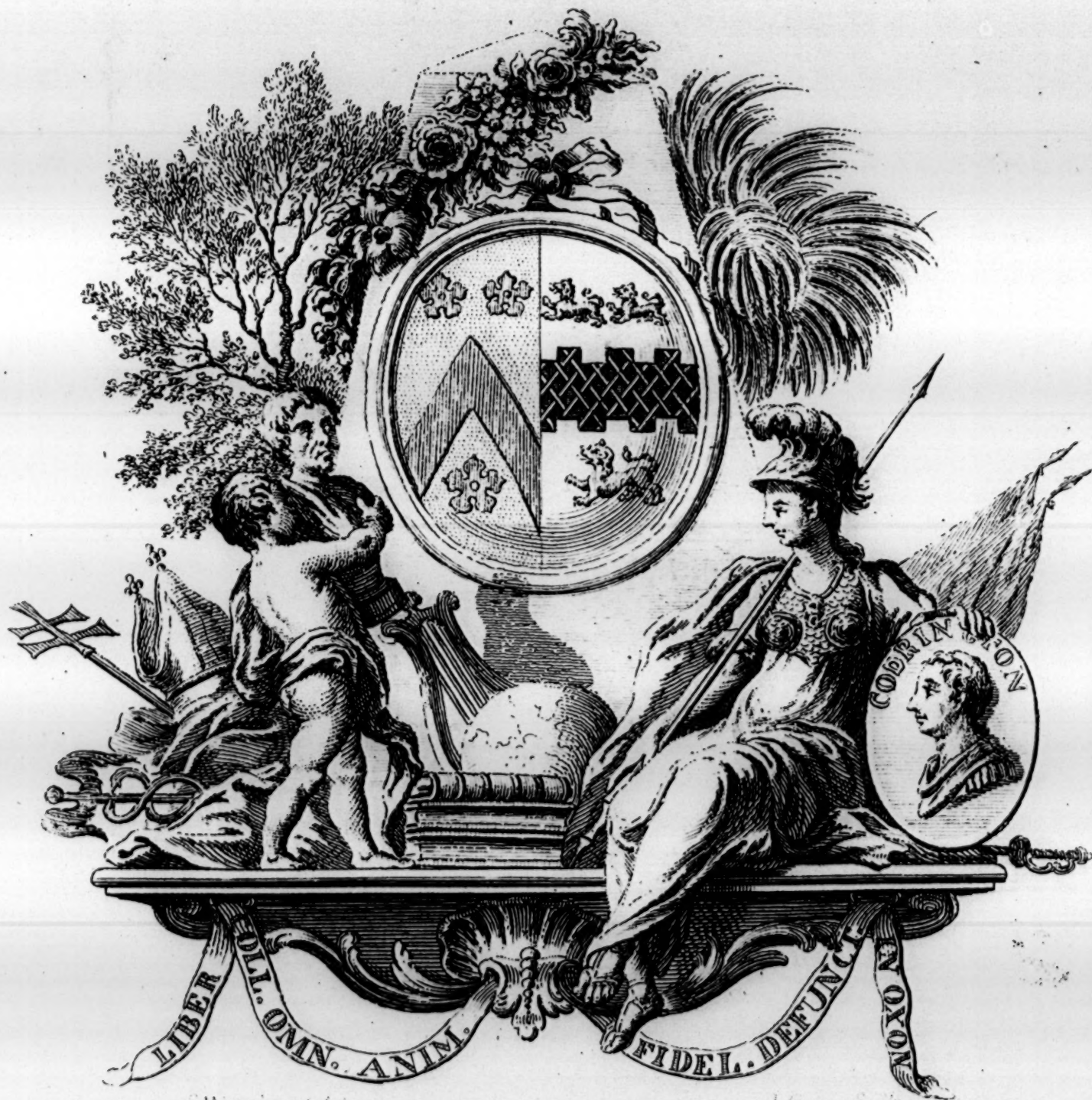
A Work pleasant and profitable for all sorts of Men, from the highest to
the lowest Degree: And never treated of in *English* but once before, and
that but briefly.

The whole comprized In Ten Books, and illustrated with Copper Cuts.

By *Ven. Mandey* and *J. Moxon*, Philomat.

L O N D O N,

Printed for the Authors, and Sold by *Ven. Mandey*, next door
to the *Salmon* in *Bloomsbery Market*, and *James Moxon* at the
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To His GRACE,
WILLIAM,
Duke of **BEDFORD,**
Marquiss of **TAVISTOCK,** Lord
RUSSEL, Baron *Russel* of *Thorn-*
haugh, and Baron *Howland* of
Streatham, Knight of the Most
Noble Order of the **GARTER,**
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of *Middlesex, Cambridge* and *Bed-*
ford, and One of his Majesty's
Most Honourable **PRIVY**
COUNCIL,

VENTERUS MANDEY

and

JAMES MOXON,

In testimony of the Honour and re-
spective Observance they bear to
that Noble Duke, humbly Pub-
lish and Dedicate this their
ensuing **TREATISE.**

To the READER.

AMong the chiefeſt and moſt uſeful ARTS, which God, the moſt wiſe Artificer, hath granted to Mankind, this Noble Mechanick Art is not the meaneſt, and yet nevertheleſs, for the moſt part, the leaſt regarded, which I much admire; it being of ſuch general Uſe for all ſorts of Men, in making of Mills of various kinds, for Grindeing, Sawing, Pounding, &c. and Engines for making Mines, and Coal-Pits, Raiſing of Water, and other heavy Bodies, likewise in making Clocks and Watches, &c. and alſo for ſeveral other Uſes, too long to inſert here. This Work hath been largely Treated of by ſeveral ingenicus Men; in Italian, French, High-Dutch and Latin, viz. Archimedes, Ariſtotle, Schottus, Stevinus, Guido Ubal-dus, Mereſnnus, Dechaſes and Caſſatus, but moſt largely and learnedly by our Reverend Country-man Dr. Wallis in his *Mechanica*, and by ſeveral others, which I omit naming; no one having writ of it in our Native Language that I have ſeen or heard of, but the Reverend Biſhop Wilkins, and he but briefly, and rather Hiſtorically than fundamentally. In the following Treatiſe we have Collected thoſe things which are moſt pertinent to the Work, and divided the whole Treatiſe into 10 Books, an account whereof you have in the following Pages; which being as kindly received, as they are freely offered, will oblige thoſe who are friends to all, but eſpecially to them that are Mathematically inclined.

V. M. and J. M.

A
T A B L E
T O T H E
Several Propositions and Series
O F T H E W H O L E
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Mechanick-Powers:

OR, THE

Mystery of Nature and Art unvail'd.

BOOK I.

THE *Mechanick Art* is a Science which contemplates about the quantities of moving Forces, and of the times in which the Motion is made.

The Centre of Gravity of any Body is a certain point within it, having the parts about it every where consisting of equal moments according to which it is born downward, and from whence if a body be conceived to be hung by a Line it resteth while it bears downward, keeping the Position which it had in the beginning, and that Line is always perpendicular to the Horizon.

PROPOS. I.

VARIOUS are the Engines, to which if force be used, their strengths are augmented in a wonderful manner, so that, that which is fit to overcome the resistance of 100 pound weight, may be made sufficient to overcome 1000 pound, yea, 2000 pound weight, and more: I will expound this Proposition, which cannot be done better than by simply exposing to view the Engines, whose forces are increased by the strength of their movers, and we will shew what Experience approves in common Engines; and because almost all Authors recal the other Powers to the Balance, we will begin with it.

Of the Ballance.

BY the *Ballance* we understand an iron Rod, hanging freely in the middle point which is called the *Beam*, or *Centre*; and the effect which daily experience teaches us is this.

Fig. 1. If two equal Weights suppose of 4 pound each be hung in the points A and B, so that the lines A C, C B are equal, they will poise each other, or be in *Equilibrio*. But if the weight F be never so little removed from the *Beam* or *Cock* C, so that the line B C be longer than the line A C, the weight F overcomes and raises the weight E; if you ask why those forces are increased by their greater distance from the *Beam*, or *Centre*, so that the distance augmented is equivalent to the weight; that is, suppose two unequal weights E and G, and let the proportion of the weight E to the weight G, be the same as the distance C H to the distance A C; and that the weight at H compensates or makes amens in the distance for that which it wants in the Gravity or weight, so that they still remain in *equilibrio*, (or equally poised) therefore it is questioned, wherefore the distance from the beam administers sufficient strength to it to resist double its weight; which is so far forth a truth, that if the line or rod C H being produced farther in certain divisions, the same weight, suppose one pound, will according to the several distances equiponderate to any weight, or number of pounds hung in the point A, and this kind of *Ballance* is in use every where, for Butchers weigh their meat by it, and Farmers their Hay, &c. Only Note this one thing, which in all Engines ought to be noted, to wit, as often as the force of the power is increased by the *Engin*, so often also is its motion increased with respect to the motion of the weight; as in the former example, while the weight G is at the distance C H, being double the distance of A C, all things being so disposed, if you remove the weight E one foot, the weight G must be removed 2 feet, since it describes an Arch doubly greater, or as great again.

Of the Leaver.

THE second *Engin* which is proposed is the *Leaver*, which is a firm body extended in length, as a Bar of Iron or a wooden Bar of firm substance, in which three things are always.

ways to be distinguished ; to wit, the power of the *Movent*, the Weight to be moved, and the point that sustains the *Leaver*, which is called *Hypomoclion* or *Prop*, being nothing but a Roller or a piece of Timber or Stone laid under the *Leaver*, to support it, even as in the Ballance we distinguish three things, to wit, the two Weights and the Beam or Cock ; whence it comes to pass that the *Leaver* is compared to the Ballance. And because the *Hypomoclion* may possess either the middle place between the power and the weight, or it may be in one of the extrems or ends, and that two fold, to wit, either so that the weight may possess the middle place, or else the power may be in the middle, therefore there are three kinds of *Leavers*.

Fig. 2. The first kind of *Leaver* hath the weight on one end A, the Power in the other end C, and the *Hypomoclion* in the middle, to wit, in the point B, and if the power happen to be equally distant from the *Hypomoclion*, with the weight, and so equally moved ; In such disposition if the power can of it self and without an *Engin* move 100 pound, and the weight A be just 100 pound, it may move that and no more ; but if the distance B C be greater than the distance A B, suppose double to it, and being so disposed, while the weight is moved one foot, the Power C performs 2 feet, then the same power being placed in C, will raise or overcome 200 pound in A.

The same proportion in a manner is said to be in the second kind of *Leaver*, for because the distance D F exceeds the distance D E, therefore the power placed in F, will be increased according proportion of the line D F to the line D E.

The third kind of *Leaver* increases not the force of the Power, but rather increases the force and resistance of the weight, and lessens the force of the power ; because the distance of the power H from the *Hypomoclion* G, is less than the distance G I of the weight from the same *Hypomoclion* ; and consequently in such disposition the power is less moved than the weight.

Of the Wheel, or Axis, in Peritrochio. Fig. 3.

THE *Wheel*, or *Axis*, in *Peritrochio* may be variously used, and this Figure expresses it sufficiently, The power will be in the point F, and the weight in the point D ; it may easily be reduced to the *Leaver* of the first or second kind ; For its *Axis* A B hath the force of the *Hypomoclion*, and because the weight is

in D, its distance will be CD and the distance of the power applied in F will be EF; Therefore the active force of the power will be increased according to the *Ratio* or proportion of the line EF to CD, that is, if EF be four times as much as CD, and the power without an *Engin* may take up 100 pound weight; it being added to such an *Engin* may take up or draw 400 pound weight; Here we shall offer no reason, but expose the precise effect and experience; Wherein we would note one thing, that the precise distance from the *Hypomoclion* doth not conferr this augmentation, but that distance from whence follows the greater motion in the power, will respect to the motion of the weight, that is, if the Power H should draw by the rope FH, the distance HE is not to be regarded, but only FE, because although the length of the rope increase and consequently the distance HE; notwithstanding from that distance it doth not follow, that while the weight is moved one foot, the power is moved more than four feet.

Of the Pulley or Windless. Fig. 4.

THE single *Pulley* increases not force, and is reduced to the *Leaver*; notwithstanding being so composed that the distance of the weight and of the Power are equal, and these distances are DB, BE from the immoveable point B; and since no *Pulley* hath motion, but about the Fixed point B, therefore the forces are not increased, if the principle we prosecute be constituted, because the power is as well moved as the weight. The only benefit that accrues from the *Pulley* in this disposition, is that the power may be more easily applied, and to shun the resistance which may happen by accident, because the rope being turn'd about an immoveable Cylinder is fretted and worn.

The Pulley may be disposed after another manner.

Fig. 5. It may be made so that the whole *Pulley* may move, supposing one end of the rope fastned in A, and the weight G, the Power F, and this is commonly reduced to the Second kind of *Leaver*, for the *Hypomoclion* is supposed in B, the weight G is in E, and the power F is in D, and therefore the distance
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of the power is double from the *Hypomoclion*, and while the weight G ascends to H, the Power F will be moved to a double distance : It is not needful here to shew all the Combinations of *Pulleys*, but only in this case to shew the double force of the power, and that force which before was equal to 100 pound weight, by this disposition may be made equal to 200 pound weight.

Of the Wedge. Fig. 6.

THE *Wedge* is an Instrument made of solid matter, as *Iron* or *Wood* ending in a sharp point or edge, As ABCDEF, some Authors strive to reduce it to the *Leaver*, in which we are indifferent, and the *Wedge* seems to be a double *Leaver* of the second kind, in which the *Hypomoclion* is in the line G H, the weight in R and K, the Power in L and M, but how ill they have resented or reduced it, we will shew hereafter; However it be, it is certain the force of the Power is increased by the sharpness of the *Wedge*, and the accuteness of the Angle, because while the bodies which have the force of the weight, go back from one another by the line R K, the *Wedge* is moved according to the line I O: Add also, that the power which is struck with a blow on the head of the *Wedge*, makes a greater motion, than the Power which is made by weight lying on the head of the *Wedge*.

Of the Screw. Fig. 7.

THE *Screw* is a most powerful Machine, or Engin, and is a Cylinder cut with a wreathed circle about it, which may be variously constituted and made: We shall not attempt to reduce it to the *Leaver*, but 'tis certain, that one man who can alone by his own strength raise 100 pound, may by this Engin sometimes raise 10000 pound. For let the weight be DE, the Power C, in the mean while that the weight is moved according to the distance which is between two wreaths, or spires of the *Screw*, it is necessary that the power placed in the point C absolves or finishes a whole Circle; therefore let the distance between the two wreaths be equal to the line N O, then seek how many times the line N O is

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contained in the circumference of the circle CKL, if it be contained 100 times, the motion of the Power will be a hundred fold greater than the motion of the weight, as is proved by daily experience.

PROPOS. II.

Aristotle's Reason, why the forces of Powers are increased by the force of Engines, is Examined.

Aristotle is the first that we know of that attempted this; we have often read his whole Treatise which he wrote of *Engines*, and confess we could never sufficiently find out the universal principle of Machines or Engines: For he attempts only to give the reason of the *Ballance*, and reduces the *Leaver* to the *Ballance*, and the other Machines or Engines he explicates by the *Leaver*: We shall do two things, First, we shall examine the Reason which he offers, as the only true and most likely for the *Ballance* in the middle. Secondly, we shall try whether those things which are said concerning the *Ballance*, may be said of the *Leaver*, and whether those things that belong to the *Leaver*, may be easily applied to the other Machines, or Engines: For he proposes some wonderful things from the Circle, and adds, that those things which are done about the *Ballance* are to be referred to the Circle, and those concerning the *Leaver* to the *Ballance*, and all other Motions concerning Engines he refers to the *Leaver*.

Aristotle reasons thus, Every Power moving to the centre of the World is born down by a right line, and the weight thrusts forward, or the weight according to its quantity contributes to such motion; but when weight is moved in a *Ballance* then it is supposed to deviate from such rectitude, and by deviation it breaks off and retards the motion pressing forward from such power, and by how much more the motion produced by such power is retarded, by so much more decreases the force of that power in order to such motion; but because that which is nearest the Beam or Cock, is also nearest the

the retaining principal, and deviates more from right motion; therefore the moving power being applied in a point near the Cock, loses more of its force; and that which is more distant from the centre or cock, partakes less of motion; besides the nature of that motion comes nearer to right motion, and therefore its force is less hindered to exercise its power, wherefore that weight which is farthest distant from the Centre is easily moved, and although it be equal to the other weight weighing against it, and less distant from the centre, it will be moved more easier; which to make more plain he institutes a geometrical Demonstration in this manner:

Fig. 8. Let the Iron rod $A B$ be the Ballance, the Beam or Cock A , about which, as about a Centre, the whole rod $A B$ is moved; and let the weight be B which descendeth by force of its own weight, and describes the arch BH ; also let there be another weight C , which while it descends by its own gravity is consider'd according to the disposition of the Ballance, to describe the arch CDY , less than the arch BEH : Suppose the weight C to descend to the point D , and draw the line DE , which let be parallel to the line AB , Suppose the weight B to descend to the point E , since the natural motion of heavy things is perpendicular, the lines FE , GD measure the natural motion of the bodies or weights, or the motion which is according to their Nature; But the lines CG , FB measure the preternatural motion, to wit, by whose force they are retracted from their lines of Direction, or perpendicular lines; but FB is less than CG ; for if equal right lines fall perpendicularly on the Same-diameter of unequal Circles, that which is in the greater circle cuts off the lesser part because the greatest circle is less crooked: Therefore while those two weights have an equal natural motion, that which is farthest distant from the Centre hath least of the preternatural motion, therefore the easier moved, and therefore hath greater force to move the other, and consequently comes to E in a shorter time, than the weight C comes to D .

Moreover he adds, because the motion of weight is equal in each, the motion which is according to nature is in it self the same to preternatural motion, but it only then happens when in the same time that C comes to D , in the same time also B comes to L ; for then drawing the line IL perpendicular, it will be as IL to IB , so DG to GC ; in the Triangles AGD , ALI (by *Prop. 4. El. 6.*) so is IL to AI , as GD to AC ; and as

A D or A C to A G or A K, so is A B to A I, therefore by division, it will be as I L to I B, so G D to G C: When therefore it happens only in the point L, that the proportion aforesaid is kept while the point C comes to D, the point B will come to L, therefore B is moved more swiftly. These are Aristotle's words, *Quam igitur ex causam ab eadem potentia celerius fertur, id quod plus a centro distat, ex iis quæ dicta sunt est manifestum.* And Question 3d. he says, *Quoniam autem ab æquali pondere celerius movetur eorum, quæ a centro sunt; duo verò pondera quod movet, & quod movetur; quod igitur motum pondus, ad movens longitudo patitur ad longitudinem, semper autem quanto ab Hypomoclio distabit magis tanto facilius movebit.*

Many things are wanting in this Demonstration, First, because the weight B is more easily moved; he concludes also, that it hath greater force to move the opposite weight, but whether he hath assigned the true cause, the comparing of the cause with the effect will shew; which that we may consider, we suppose the line A B to be double the diameter A C, therefore G C will not be double of the line F B, therefore will not the preternatural mixt motion in the weight C, be double to the preternatural mixt motion in the weight B, and therefore that cause is not most likely and true from whose Comparison the proportion of the effect and cause is not shown: For it is certain, that the weight of 1 pound in the point B will be equivalent to the weight of 2 pound placed in the point C or T; Whence we deny this conclusion can follow from that antecedent, that the weight which is farthest distant is easiest moved, therefore if it be distant a double distance, it will obtain a force doubly greater; and neither do Mathematicians deduce their conclusions after that manner; although while the distance increases the facility to motion should increase, it doth not follow that it increases in the same reason or proportion: And so we deny the facility to motion of the weight in B to be double, to the facility to motion which the weight hath in C; because that contrary which is mixt in C is not double to the contrary which is found in B.

Secondly, Aristotle speaks of the swiftness of Motion, and from the Swiftness he concludes to the Power moving, which we shall shew to be false. It is certain, that if two Weights should be successively in the point B, one of one pound, and the other of two; nevertheless they will be equally or with
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equal velocity moved downwards, if they are of the same matter and figure, or if there be found some difference, it will not be in proportion to the weights; Wherefore although we should grant the weight B to be moved with a velocity double to C, yet notwithstanding the force of his reasoning doth not conclude it to have greater force to move the other.

Thirdly, what is said in demonstrating the weight B to be moved with a double velocity or swiftness to C; he either understands while they are joined in the same ballance, or he understands it while they are seperate and in two ballances: If he means the first, there was no need of so much reasoning, neither doth that preternatural mixt motion help any thing. But if these two weights are lookt upon as Seperate, or in divers ballances, that we may examine what force they have, it is fals that that which is farthest distant, is moved with a double Swiftness. *Aristotle* knew not the doctrine of *Pendulums*, for the swinging of divers *Pendulums* are perform'd in equal time, to wit, if in the same time that the weight B being left to its own nature comes to L, in the same time the weight C will come to D, also they absolve each his quadrant in the same time; Notwithstanding if there be two pendulums C and B, and the Swinging of the weight B be longer than the swinging of the weight C, so that if the lesser dure 2 minutes, the other weight B takes up almost 3 minutes in perfecting its vibration; Whence howsoever he explicates this Demonstration, he wavers in all things, and is far from *Mathematical* conviction. Moreover we will shew, that although the demonstration have some force in that part of the Circle, yet it obtains none in others; for in the first place let the lines O H, Y K be equal, and draw the parallel lines K R, O P; It is certain, that O P is greater than K R, therefore if there be a weight in R and another in P, one descends in Y and the other in H, the preternatural motion will be more in the weight more remote, notwithstanding in this case the weight which is at greater distance, obtains greater force; therefore that which hath greater force, is not begat from the lesser mixture of preternatural motion; which may better be perceived in the points 3 and S; for if the weight 3 move to S, and the weight X to T; the lines V T, S Z measure the preternatural motion, and the lines V X, Z 3 the natural motion, and the weight X least distant from the centre or *Beam*, will be more moved by the natural motion than

the weight 3, and therefore easier, whence it obtains greater force.

Whoso diligently considers the parts of each quadrant, will find this mixture of contrary or preternatural motion to be less in the lesser circle than in the greater; and the reason is, because although towards the Diameter A B the greater Circle comes nearer to a vertical line, yet towards the diameter R H it comes nearer to an horizontal line; and so much for the first part of this Proposition.

Fig. 9. That which belongs to the second part of the same Proposition, to wit, although we grant that, which *Aristotle* assigns for the true cause, why in the ballance the weight most distant from the centre hath greatest force, to wit, that it hath less of the contrary or preternatural motion, yet notwithstanding we do not find the reason to be the same for the *Leaver*. For the power A, may move Circularly, so that it have nothing of Preternatural motion, since the power of an *Animal* is indifferent to any different place; therefore since it hath no preternatural motion admixt, the force of the greater Circle doth not move easier than the lesser, which notwithstanding is contrary to all experience.

Secondly, that kind of *Leaver* only in which the *Prop* or *Hypomoclion* is found between the *Power* and the *Weight*, may properly be reduced to the Ballance, but the other kinds not so properly.

Thirdly there are divers *Machines* or *Engins* which are difficult to reduce to the *Leaver*, and by that means to the *Ballance*; and first for the *Wedge*, We ask whether there be a *Prop* or *Hypomoclion*, and to what kind of *Leaver* it is reduced? What Circle is described from it? What is its preternatural motion? What its natural motion? Surely there is in the *Wedge* the impression of the weights resistance to be exercised in the parts in which the body touches, as in K R; We ask in what point is the *Prop*? Where the length of the *Leaver*, Which if it be increased according to the common rules of the *Leaver* the Virtue of the Power will be increast? If 'tis said the point of it is the *Prop*, we will shew 'tis not, because if the point of the *Wedge* should be cut off, yet nevertheless the *Wedge* would have its whole force; If 'tis said the line K L is the length of the *Leaver*, 'tis false, because although that length be cut shorter, yet notwithstanding the virtue of dividing is not deminisht which is
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in the *Wedge*, therefore which way soever you turn the *Wedge* you will scarce reduce it to the *Leaver*.

Fourthly, Much less do we own the comparison of the *Leaver* in *Screws*, which may rather be reduced to the *Wedge*; for if you own the *Axis* of the *Cylinder*, about which the screw or spire is circumvolved to be the *Hypomoclion*. The distance of the *Spires* or *Screws* from that *Axis*, will be the distance of the weight from the *Hypomoclion*, according to which distance the resisting power of the *Weight* is measured, whence it follows in the *Screw*, the *Cylinder* that is less than the other pairs, more easily overcomes the resistance of *Weight*, which nevertheless is false: For neither is this the measure of the resistance of the *Weight*, or the virtue existing in the *Screw*, but ought to be deduced from other principles, to wit, from the compression of the *Spires*, for when the *Spires* or *Helices* are more thick or closer together, the stronger and more powerful are the *Screws*; Therefore we must seek another principle of *Machines* or *Engins* more clear and easie, which being once constituted, the power of every *Machine* or *Engine* well be unfolded, and the proportion of it to the resisting force of the *Weight* will be detected.

PROPOS. III.

Archimedes reason Examined.

Fig. 10. **A**rchimedes in his sixth Proposition, *Equiponderantium*, and many others after him, have attempted to establish as the chief principle of *Machines* or *Engins*, that in the *Ballance*, if the weights and their distance from the *Centre* be reciprocal, they consist and counterpoise each other.

In the first place, we referr this to be settled by the reverend Father *Leotanudus*, and what power his demonstration may obtain; suppose *A B* to be a *Rod* of a like weight in every part, and divided in the middle in *C*, and understand *C* to be the *Centre of Gravity*, and *C D* to be drawn through perpendicular to it; by the point *D* draw an iron rod *D E*, which let be so alike for weight as to consider it wanting all weight, and

let D E be greater than the half of C B, and make G D equal to I B, and H K equal to the line A H; when the lines C I and I B (equal to H C) are added, H I and C B will be equal, and so H I will be equal to the half C B, and the remains A H, I B together are equal to the other half; and because A H, H K are equal, being taken from the two equal aggregates H K, K I, A H, I B, the lines K I, I B will be equal. Let two Threds or Lines H G, I E hang up the rod A B, and fasten it to the rod G E in the point D, which answers the Centre of gravity C, the line from whence 'tis hung up being perpendicular with the line D C, answers to the Centre of gravity C; A B will remain equally poised, or in *Equilibrio*.

The Demonstration. Let the Rod A B be really divided in the point K, that is, seperate the Union, or cut it in two. First, since A H, H K are equal, neither will preponderate or out weigh the other; moreover since K I, I B are equal, neither will prevail, wherefore as yet they will remain in *Equilibrio*; therefore the whole line will remain in the same manner as before, being hung by the same point D, therefore as yet the whole line will be in *Equilibrio*: But so is the distance H C of the weight A K from the Centre, to C I the distance of the lesser weight K B from the same Centre, as the weight K B to the weight A K; for so is A K to K B, as its half H K or C I is to K I, or H C its equal; therefore we have this in *Equilibrio* while the whole weight A K is to the weight K B, as the distance I C to the distance H C reciprocally, which was to be demonstrated.

We will consider hereafter whether this Demonstration convinces, and assumes nothing as now proved, which notwithstanding should be demonstrated.

Fig. 11. Archimedes a little after endeavours to prove this somewhat otherwise, and he supposes the Iron Rod to be A B, and he subtracts from its gravity that which is hung in the middle point G; he hangs 6 equal weights, here 3 and there 3 at equal distances, 'tis clear that they are in *Equilibrio*, he supposeth also that all these weights are alike, and equidistant between themselves: Also he supposes any weights to gravitate and operate in the same manner, as long as they retain the same common centre of gravity.

The Demonstration is clear, in case the weights be distributed according to the disposition unfolded, before which common

mon centre of gravity of all the weights together will be in G; but if you consider 4 weights B C D E whose centre of gravity will be in the point I, and the centre of gravity of the weight F L is in H; wherefore the weights will gravitate in the same manner, howsoever they are disposed, they keep in a manner their centre of gravity in the same point H; therefore conjoin the weights F and L in the point H, and conjoin the 4 weights B C D E in the point I, or so about the point I, that their centre of gravity may be the point I.

Fig. 11. All these weights will gravitate in the same manner in this disposition, as in the former; But in the former they were in *Equilibrio*, therefore in this second disposition they will be in *Equilibrio*: But in the second case, so is the weight B C D E to the weight F L, as the distance G H to the distance G I therefore it will be in *Equilibrio*, when as weight is to weight, so is distance to distance reciprocally.

These Demonstrations are ingenious, but they do but suppose those things to be the principles of *Engins* which is sought: For first of all in both Demonstrations he mentions the centre of gravity, but it is not known what that centre is, and this centre of gravity can hardly be proved, unless there be constituted a common principle of *Engins*; In the first, although it seems clear enough that the division being made in the point K, the lines A K, K B lie in a direct line, because that both parts A H, H K and K I, I B are equal; Notwithstanding it doth not appear to me that they ponderate in the same manner, the division being made as before: For the part C K before the division, exercised its gravity with the other part K B, and as I may say, was staid by its parts: But the *Union* being loosed, it exercises now its own gravitation, together with the other part A C; Whence although it were before in *Equilibrio*, it follows not that it being seperated the *Equilibrium* remains.

I say the same of *Archimede's* demonstration, for I cannot grant that weights have the same manner of gravitations they should have among themselves, and the same gravitation they should have respectively to another weight, so often as they change not the proper centre of gravity: If in one case, one of them will be found on one part of the centre, and in the other it will decline to the other part; that is, 'tis doubted whether the weight E transported in I being united with other weights B C

D in..

D in the same point I, hath the same force, and not greater, or lesser.

And that we may shew the Principle sought, the definition of the Centre of gravity is commonly thus given, to wit, 'tis the point dividing the heavy body in two parts of equal moments, but moment is not simply the weight of body, but grows together from the weight and distance, therefore to the understanding of the Centre of gravity the constituted principle is supposed, whose reason we seek; *viz*, Why weights by reason of their greater distance from the centre have also greater force to move.

P R O P O S.

The true Reason of increasing power by Engines.

Fig. 12. **N**One will require of us a strict demonstration here, because we are busied in phisick matter, and we inquire the principal of natural and sensible motion, which perhaps will not presently occur; one thing I must say, that although I do not effect the thing, yet by removing things out of the way, I shall open a door to let into it; therefore I shall attempt many methods, that so if one arrive not at it, I may make way for another: First, in the ballance I will endeavour to settle that common maxim, while the weights and distances from the Centre are reciprocal it is in *Equilibrio*; As if in the ballance A B the weight A of two pound is to the weight B of one pound, as the distance C B of two feet to the distance A C of one foot. If from a piece of timber, you hang a ballance from the point C, to be in *Equilibrio*, so that you remove it so far from the Centre to answer the addition that should be made to the weight, that is, if the weight of one pound hang in the point D, and in A a weight of 2 pound, to make them in *Equilibrio* the same weight should be added, and in stead of the same weight you may add the same distance, or so remove it from the Centre that C B be double to C D; Thus a weight of 1 pound being placed in B, it will be again in *Equilibrio*, experience shews this, but the reason is to be sought.

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First, I suppose any heavy body to resist a motion upward, and the greater it is, the greater motion it will resist; so that a greater violence or force is required to move upwards a weight of 1 pound the space of two feet, than to raise the same weight but one foot high, or at least it requires a force to be applied of a longer continuance of time.

Secondly, I suppose while the weight is moved downward, the weight on the other part of it may move somewhat upward, so that it may overcome the resistance which the opposite weight hath to motion upward; also while a weight is moved more down or lower, it produces a greater *Impetus*, together with that motion which would have bin if the motion had bin less; this last part of the supposition seems hard, therefore I shall explain it more largely.

I Suppose thirdly some productive cause of motion to be given, distinct for the most part from the principal agent to which motion is ascribed, as in things projected or cast from one, I think in good *Philosophy* it can scarcely be denied, such like cause besides motion which is successive, and no part whereof exists with the other, and therefore the other cannot be the cause, for every effective cause acteth not but when it exists; Therefore while its action exists, it self also exists, and while its action exists the effect exists by such action produced: Therefore while any effect is produced and exists, its cause exists, but while one part of motion exists, another part existeth not, therefore one part of motion cannot be produced from another, and therefore another cause of motion ought to be admitted, but this cause is not the principal agent to which motion is attributed, for first in things projected, the hand which throws the stone is not any more join'd with the stone in conveying it through the air, and therefore produces nothing further, neither can that be attributed to air that some do, to wit, that the hand while it Impels the Stone, impels likewise the contiguous air, and that air other air, untill it make a Circulation, and this last air carries the Stone farther; but on the contrary, in the same precise Moment and time wherein the Stone joined to the hand moves the air just before it, (since Penetration is not granted) in the same time also this air moves the following air, and so consequently makes the whole Circulation at the same precise time, and there is found only the priority of dependence: Suppose the motion of the Stone to be from the point

point A to B, and in the same precise time it makes the whole Circulation, and the air which was in E follows in F, neither hath it greater force to farther motion than it hath from the Stone; from the following time I ask whether the motion of the air F depends on the motion of the Stone, or the motion of the Stone on the motion of the air, if you say the first, I demand again from whence the Stone is moved, if the second, I ask from whence the air is moved, for the past motion of the stone cannot be the cause of motion of the present air, therefore it is necessary to say something is added to the Stone from whence it is carried through the air, and this I call *Impetus*, or force, whatsoever it be.

Moreover I will shew, *Impetus* being granted, *viz.* While a body descends it seems to me a reason to be alledged, why in the first space of time the body descends one foot, in the second three, in the third five, in the fourth seven, and so on, unless the continual production of some *Impetus* be admitted, which is the immediate productive cause of motion, which *Impetus* is permanent and may be increased.

Also it follows, that a second *Impetus* is not produced, unless the first hath and produces some motion, let two weights be suspended in the air, each produces some *Impetus* in it self, and also in the body which they hang on, let one weight be moved by the space of three instantes, or moments, so that after that third instant it hath an *Impetus* as three, let down the second weight in the begining of the fourth Instant, wherefore it hath not the *Impetus* as three as the other weight; because (you'll say) it remains unmoved, and the other is moved: therefore motion is the condition to the producing a farther *Impetus*, at least such motion whose *Impetus* is according to nature.

Which I shall likewise make good from other experiments: First, why while I drive a nail with a hammer of a longer handle I produce a stronger blow, or stroak, in like manner, if I lift the arm and the hammer higher, so that it describes a greater circle, the stroak is made more valid and strong; no other reason can be given, but that by the greater motion (whether as the condition, or as the cause, it matters not) a stronger *Impetus* is produced, so that the power unless it be moved, never produces in the begining of its motion such *Impetus* in the nail, how great soever the endeavour be, as it produces

produces while it hath some motion; so that if 10 men press with their weight upon a nail it doth not enter the wood so well, as if it be drove with an hammer by one man.

While any one runs a pace, if his feet be stopt he cannot chuse but fall; and so a horse on full speed can scarce be held in, whence they lift up their fore feet, as it were a contrary motion to aswage every conceived *Impetus*; While a boat is carried with a great *Impetus*, and is suddenly stopt at the shoar, all that are in the boat are moved, because now the conceived *Impetus* is conveyed farther they bend forward being stopt.

And I shall shew that a weight of one pound placed a little farther from the Centre than another weight of one pound, will raise it up; suppose two weights equal each to one pound, so placed in a ballance that one is double the distance of the other from the Centre; whence I thus argue.

The weight of 1 pound while it moves downward 2 feet, may overcome the resistance which a weight of one pound hath to motion upwards one foot: therefore if they are so fitted in the ballance, that while one is depressed 2 feet, the other is only raised 1 foot, it raises that upward; The antecedent is proved, while the weight of one pound is moved downwards 2 feet, its active force or *Impetus* which it puts forth together with such motion, is precisely equal to that resistance which the opposite and equal weight hath to motion upwards two feet, but the resistance to motion upwards one foot is less than to motion upwards two feet; therefore while one pound weight is moved downwards 2 feet, the other pound weight may be moved upward one foot; But when two equal weights are so placed in a ballance, that one is doubly distant from the Centre to the other, it also effects a double space to that which its opposite effects; therefore we have one reason now, why between equal weights that which is farthest distant from the Centre is depressed, and raises up its opposite weight, which may be also proved in this manner; when two unequal weights are equally distant from the Centre the greater raises the lesser, because the parts of motion downwards are more than those upwards, and in like manner when equal weights are so placed in a ballance, that one is farther distant from the Centre than the other, the parts of motion downwards will be more in one than the parts of motion

upwards, are in the other (or its opposite) therefore the weight which is farthest distant from the Centre will raise the other opposite being equal to its self.

The motion upwards of heavy things is against nature, and the violent motion of them downwards is agreeable to nature; but how much that is which is against nature, so much is the resistance to that; and how much that is which is agreeable to nature, so much is its inclination and active force to overcome the opposite resistance; therefore where there is a greater motion downwards than the motion upwards, the active force of resisting will overcome.

The second reason is; a greater *Impetus* is required to move the same weight a greater space than a less, whether the whole *Impetus* be produced together, as happens in things projected or thrown; or successively, as when a weight is drawn.

Also a greater *Impetus* is required to move a greater weight some space, than to move a less weight the same space; whence I thus argue, an *Impetus* which is required to move a weight of two pound one foot, is double to the *Impetus* which is required to move one pound one foot; But the *Impetus* which is required to move one pound, two feet, is in like manner double to that which is required to move one pound one foot; therefore the *Impetus* which is required to move two pounds one foot, is equal to the *Impetus* necessary to move one pound two feet, for those same things which are doubled are equal among themselves: But when two weights are so placed in a ballance that the weight of two pound is distant from the centre one foot, and the weight of 1 pound is distant two feet; while the weight of 1 pound is moved downwards two feet, the weight of two pound is elevated one foot; and one pound weight as moving downwards two feet is in *Equilibrio* with one pound moving upwards two feet: Therefore one pound moving 2 feet, will be in *Equilibrio* with 2 pound moving upward 1 foot.

And that we may render the same reason more universal, and that we may apply it not only to weights and ballances, but that we may extend it to all *Engins* in general: Suppose as before, by how much more the power is that is moved, by so much the greater and stronger is the *Impetus* produced; therefore if a power while it is moved 1 foot can move 100 pound 1 foot; while the same power is moved two feet it will move

200 pound 1 foot; to clear which point, suppose for explication sake a certain opinion rejected by most *Philosophers*, to wit, that time increases or grows from indivisible *Instants* succeeding each other; suppose likewise that which necessarily follows from such an opinion, to wit, the slowness of motion is posited in more or less little *Staies* of rest, which opinion I do not propose that in it I may found my reason, but only that I may shun that confusion which the common sentence begets, concerning the continued composition from parts infinitely divisible; for when they treat of this infinity, 'tis no wonder if they mix obscurity and darkness together; Therefore suppose a power which while it is moved one point may move 100 pound one point, and being fitted in an *Engin* so that while the power is moved two points, the weight is moved only one point.

In such a supposition, the power will be moved the space of one point, the weight all the while no ways resisting such a motion, because the weight as yet is at rest, but when the power is moved to the second point, it hath a double *Impetus*, viz. the *Impetus* produced in the mean time while it is moved through those two points, but a double *Impetus* moves a double weight; therefore the power which is moved two points will move a double weight one point, if it be so fitted in an *Engin* that necessarily its motion ought to be double to that which follows in the weight.

And although this opinion Concerning continuals should not be true, and the power should never be moved but the weight should be moved although slowly; nevertheless since a power exerts a greater *Impetus* when it is most moved; as often as the motion is greater in it than in the weight, so often the *Impetus* will be greater in it, than if it had bin moved equally with the weight; but a greater *Impetus* can overcome a greater weight, therefore a greater motion of a power compared with a lesser motion of a weight can also overcome a greater weight.

To make it clearer, Suppose, to move a weight of 100 pound one foot, an *Impetus* be required as 4, which the power A may produce, and as I may so say, to lift it up while it is moved one foot; there will be required to move a weight of 200 pound one foot, an *Impetus* as 8, but an *Impetus* as 8 is produced from a power if it be moved 2 feet; For more *Impetus* is produced from a power while 'tis moved two feet than while

'tis moved one foot, therefore that principle remains, *viz.* The Power as moved 2 feet effects the same, as two powers which are moved only 1 foot; and we must not think *Impetus* to be so fluent of nature, as not to maintain and as it were heap together, that is, if the power be moved for some time it should not increase, also its intensive *Impetus* is not resisted by such *Impetus*; in like manner, a weight is not supposed so to resist a lesser motion, as a greater; whence if a power be so compared with a weight, that while it is moved 1 foot the weight is necessarily moved the same, and the resistance of the weight is greater as moving one foot than the *Impetus* which is produced from the power being moved 1 foot, no motion follows; but if an *Engin* thus distributes the same *Impetus*, that the whole be Employed in moving the same weight half a foot it will make some motion.

Nevertheless because this thing is of so great moment, and contains the most universal Principle in nature, therefore 'tis worth our while to prosecute the thing a little farther, and to apply it in every part that it may appear more plainly.

I suppose first, that 'tis equivalently the same thing to apply a motive power as one, successively to move a body, suppose the space of 5 feet, so that it move in the first time the space of 1 foot, moreover the same power moveth in the second time by another, and so on, and to apply five moving Powers Successively as one; of which, to wit, the first moves in the first time 1 foot, the second in the second time following, the third by the third, and so on; for the moving power as one if it be applied to the second time, may as well move another also like it self, therefore the same will be Equivalent whether the same motion continue, or another like to it be Substituted.

Secondly I suppose to move or sustain a body, to be the same, as to apply five powers each of which is a power as 1, and to apply 1 so that it may be a power as 5; as if in one ballance you put a body of Gold of one foot, the same will out weigh 5 bodies of each 1 foot of another matter, which is five times lighter than Gold; for neither hath the moving virtue in it self, as the first quality; for if 5 heats or warm things are put as 1, they can never be produced in the Subject but as one heat: But and if 2 Powers are sufficient to move each of them a weight of 100 pound; If they are joyn'd and

concur

concur together they will overcome or move a weight of 200 pounds; This rule is common in all Equivocal Agents, so if the powers of two candles in some determinate place, each of them produces 1 degree of light acting together in the same place they produce a greater degree of light; so while the Sun in an Eclipse is hid in some parts, the light Shineth more weakly, therefore in these cases extension begets intensification, or is equivalent to it.

Suppose two men move unequally, to wit, with a double velocity one to the other; what is in one that is not in the other; And first it is certain that the motion of the one is always double to the other, so that while one is moved one foot, the other only moves half a foot; and while the first passes over half a foot, the other passes over a quarter of a foot; and in whatsoever time assignable, the parts of motion in the one are more than in the other, whence 'tis certain in the second place, if the motion of the power confers to this that it move the opposite weight, while the power hath greater motion it produces a greater *Impetus* in the opposite weight, from whence the argument may be formed.

A power advances its force by motion, therefore while 'tis moved with a double velocity, 'tis equivalent to a double force, but a double virtue or force can move a weight doubly greater, or as great again, therefore a power moved with a double velocity can move a weight doubly greater; the first Antecedent is certain, for a power however it be applied will not move unless it be moved, whether its motion be the condition to this that moves, or whether the motion it self be the immediate cause of motion, it matters not; neither is there need to examine these things, since divers explications arise from divers physical principles: For some acknowledge no motion which takes not its rise from *Impetus* or force, and consequently to produce a greater motion in a power, they require a more stronger *Impetus*; therefore if a power be moved with a velocity double to the weight, it produces an *Impetus* doubly stronger to that which it would have had if it had bin moved equally with the weight: But if it be moved equally with the weight, the *Impetus* which is produced in it self should be sufficient to move 100 pound such a space; therefore if it be moved with a double velocity it will move 200 pound the same space; being explained, we'll Suppose a free Power to impel lightly some weight,

weight, so that by the force of its impression it is not moved, it will use a greater endeavour and at length moves it. I ask what makes that greater endeavour unless a more stronger *Impetus* be produced (supposing always that such *Impetus* is granted) but if the power it self be moved more swiftly, it produces a greater *Impetus*: Therefore by the greater motion of a power is adhibited that which is necessary, that a weight may be moved doubly greater (or as great again) each part is proved, to wit, while any body is moved more swiftly a stronger *Impetus* is produced; or the intense motion being Secluded what way soever from *Impetus*, the succession of so much local motion is agreeable with intensification; For the velocity of motion is some perfection which cannot be explicated, because of the succession of motion, and the infinite divisibility of time. Notwithstanding in each opinion, velocity or Swiftness is said to be some perfection of motion: For suppose in Fig. 14 some motion in Angles, in as much as some think them indivisible, let A B C D a potent angle in one instant also indivisible be so moved, that leaving the former space A B C D it possesses the next following C D E F, Suppose another angle or as some call it, a Physical point G H K I be so moved in the same indivisible instant, that leaving the former-space G H K I it possesses the space L M O N, Surely the former motion is a more perfect motion than the second, and therefore if there be required an *Impetus* to motion, there is required a more stronger to effect the first motion than the second: But if no *Impetus* be required, but immediately motion be produced from the power, there is required a far stronger endeavour to obtain the former than the latter; Wherefore to conclude the greater endeavour of Power moveth a greater weight than a lesser but a greater endeavour of power is advanced while 'tis moved swiftly than while slowly, therefore while a power is moved swiftly, it also moves a greater weight.

Also the first consequent is plain, to wit, (while a power is moved with a double velocity 'tis equivalent to a double power) for sure it is, while any power adhibits or uses an endeavour doubly greater, 'tis equivalent to two powers each adhibitting or using an endeavour doubly lesser. So one horse if he endeavours much, may draw a determined weight, which he may draw twice as easy, and without so great endeavour, if another horse be joined with him to assist. Wherefore if it be
 moved

moved more swiftly it will be equivalent in order to move a weight of a greater force, although sometimes the weight doth not increase its motion; for if the motion of the power be increased, the motion of the weight is equally increased. A power moved more swift will indeed be equivalent to a greater, but all that perfection which happens to it from motion relates to the making the motion of the weight greater, for a weight of a greater motion resisteth more, therefore in motion these two are always taken for the same, to wit, to move a greater weight to a less space, and a less weight to a greater space; for as to move a greater weight a greater endeavour is required, so to move a weight to a greater space, a greater endeavour is also required. The whole artifice of Engines then consists in comparing the greater motion of the Power with the lesser motion of the weight, and according to the proportion of excess the Force of the Powers are increased; because powers increase not their force but by motion, and therefore motion doubly swifter, produces *Impetus* doubly greater.

PROPOS. V.

Moveable bodies are equal in force whose Magnitudes and Velocities are reciprocal.

IT is certain, that the same body moved with unequal swift-ness, will have unequal force; also a greater body moved with the same swiftness as a lesser, will have greater force; and we see likewise in Engines that weights may be so disposed from one place to another, that the motion which is made from one hath the same proportion to the motion of another; and also that weight to weight is made reciprocally in *Equilibrio*, so that the double celerity or swiftness of one pound, will be equivalent to the Subduple celerity of two pounds; We may also transfer the same principle to other moveable bodies, although they are at liberty, that is not being disposed in any *Engin*: For it hath not less force when it is free and loosed from *Machines* or *Engines* than when it is fastned to some Body,

but

but 1 pound with the velocity as 2. is equivalent to 2 pounds having the velocity as one : Therefore also without an *Engin*, a moveable body as 1 with a velocity as 2, will effect the same as a moveable body as two with a velocity as 1. The reason is, because the motion or degree of velocity is the same in both, in a greater body they are fewer in each part; in a lesser more. Neither is there any other reason, why while they are joined in *Engins* they are of equal force, and one extension compensates another, and without an *Engin* the same will not happen.

Wherefore the moments or forces of equal bodies, or the parts moved are to one another, as their velocities; and equal velocity, as the magnitude of bodies; for commonly, moment and force, and parts moved, signifie the same, except sometimes moment likewise is attributed to bodies at rest, which have notwithstanding an aptitude to motion, wherefore what we shall say concerning moments may be said of forces.

If 2 unequal moved bodies be compared, their force or moved parts will be in proportion compounded of the proportions of the bodies, and of their velocities, because every part of a body is supposed to be moved with the same velocity, or degree of force; whence it happens, if the motion of one body be communicated to another equally, the velocity will be equal, if the velocities of the greater and the magnitudes of the bodies be reciprocal.

Whence we conclude, if a moved body runs against another body at rest all reflexion being excluded, to wit, if each body be soft, they proceed together, and the velocity of the former will be to the velocity of the aggregate of the whole, as the whole aggregate to the first movent reciprocally; For since in the former there are so many degrees or parts of motion, and each of its parts are distributed in the aggregate; to get the velocity of the first movent, the quantity of motion which is always the same must be divided by the number of parts of the aggregate; Therefore the same number of parts of motion is generated from the aggregate; in its velocity, as from the first movent in its velocity. Therefore if you dispose the aggregate, the first movent, the velocity of the first movent, and the velocity of the aggregate, since the rectangle of the first and the last is equal to the rectangle made of the 2 means; so will the aggregate be to the first movent, as the velocity of the first movent to the velocity of the aggregate.

We

We must reason after the same manner in other cases which may happen; as if there be two equal movents) or bodies moved) which are born in the same part, one hath the velocity as 4, the other as 8, and the more Swift incurs or meets in the less Swift; I say after the meeting, the velocity of the Aggregate is as 6; for since the Bodies are equal, the parts moved will be as the velocities 8 and 4; wherefore the motion in them will be as 12: but after the meeting the parts moved ought to be the same so many, therefore the motion in the whole aggregate will be as 12, and in each body as 6; therefore the velocity of the least, before their meeting was 4 and afterwards 6; and of the greater 8 and after meeting but 6.

Thirdly, if two equal bodies with equal velocities meet each other, excluding all reflexion, they will rest, because these velocities meeting one another, destroy each other, as when you put contrary qualities in the same Subject.

Fourthly, if 2 unequal bodies, suppose 2 globes one of one pound weight and the other of 2 pound, meet each other directly with equal velocities, suppose as 4, the Aggregate follows the direction of the greater, and the velocity will be as $1\frac{1}{3}$, for the quantity of motion in the greater is as 8, in the lesser as 4, while they meet each other the motion of the less as 4 detracts so much from the greater, therefore the quantity of motion remaining is as 4, to be divided by 3 pounds, there will be in each pound, one degree and $\frac{1}{3}$.

Fifthly, if two equal bodies with unequal velocities meet each other, suppose one hath velocity as 2 the other as 4; after meeting, Secluding reflection, the quantity of motion remaining will be as 2, each being divided, and therefore the aggregate will be moved as 1.

Sixthly, Suppose two unequal bodies one whereof is one pound, and is moved with a velocity as 3: and the other is 2 pound, and hath a velocity as 4; the quantity of motion in the first is 3, In the second 10, for when they meet, the lesser quantity destroys so many degrees of t'other as it contains it self, therefore, there remains 7 to be divided by 3 pound: Wherefore in the whole aggregate there will be 2 degrees and $\frac{1}{3}$ of velocity.

Fig. 15. If 2 unequal Bodies be placed in two equal Branches or Arms of a Beam (as a pair of Scales) I say the velocity of the greater only will be to the velocity of the aggregate, as the aggregate to the greater weight. Suppose a

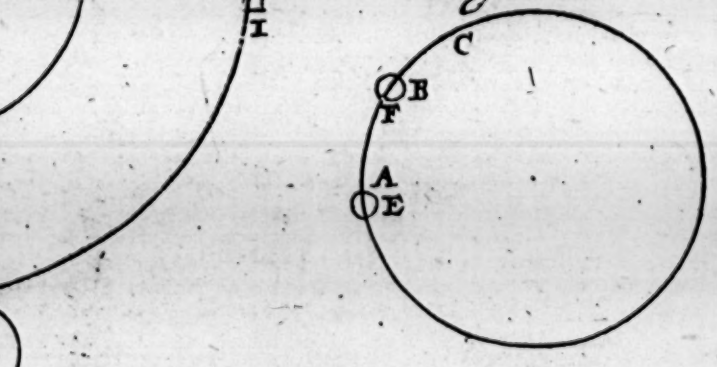
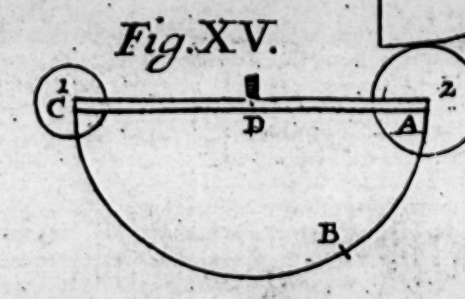
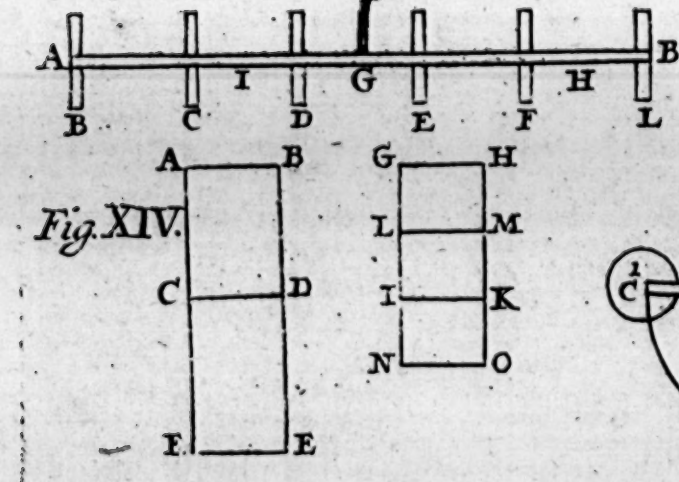
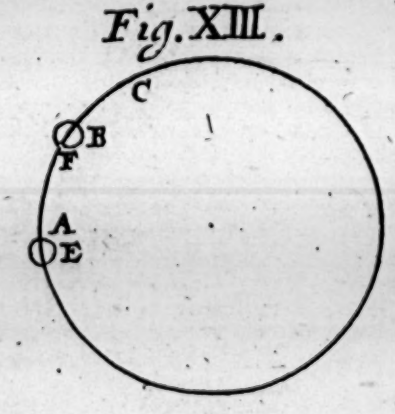
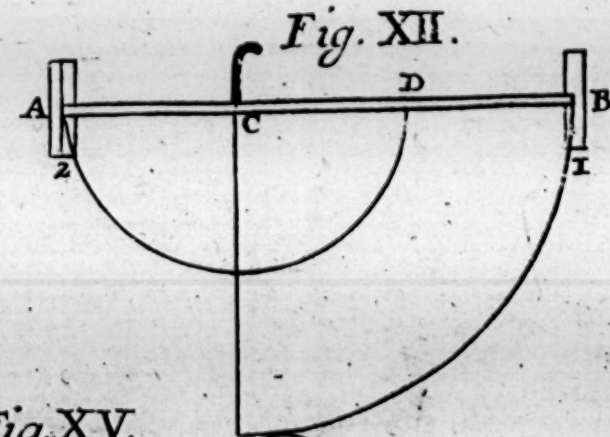
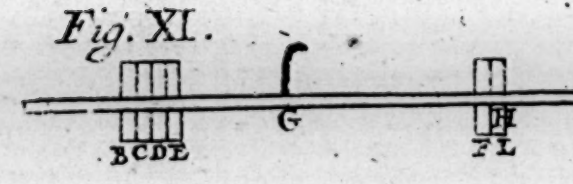
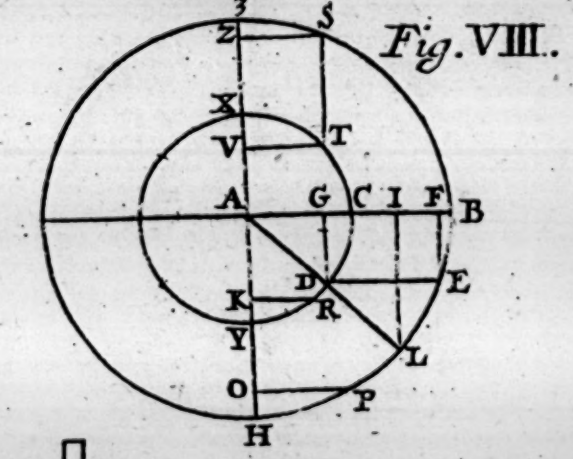
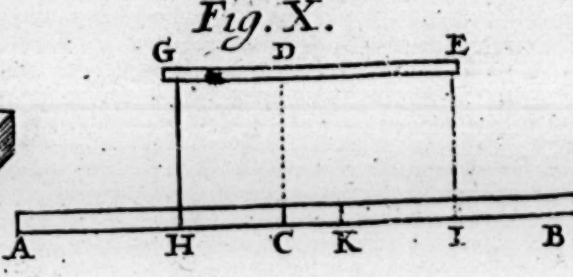
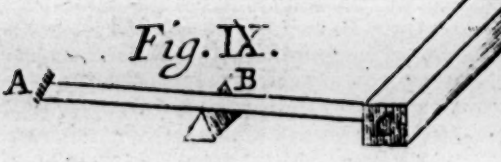
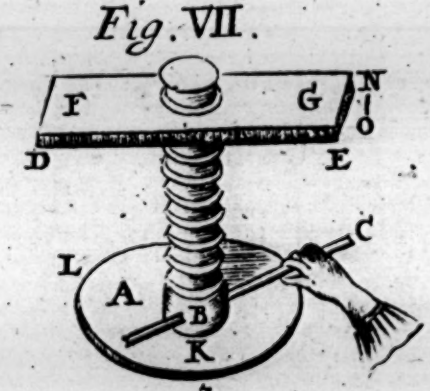
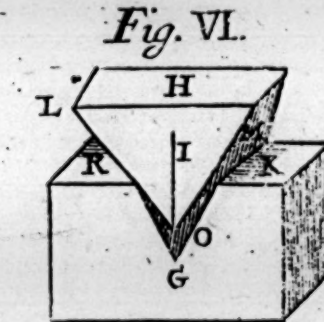
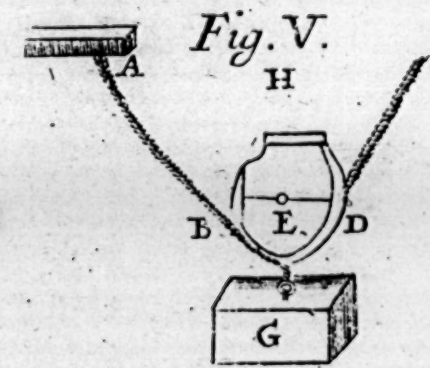
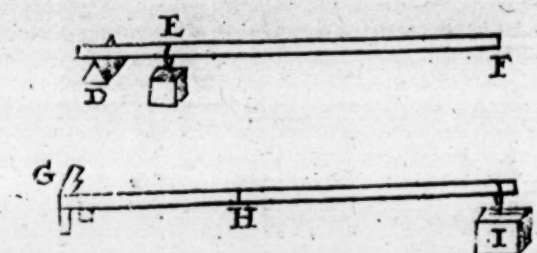
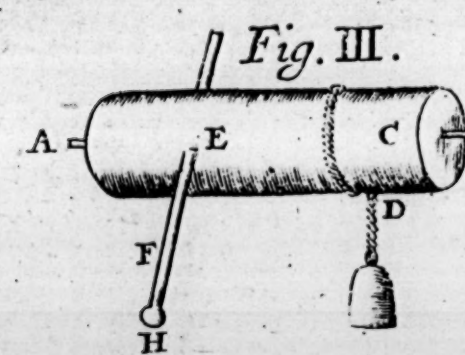
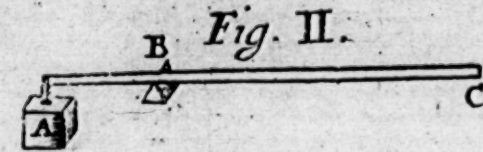
weight of two pounds, which if it be moved alone from A in B with a velocity as 4. Put on the other part a moveable body as 1, which suppose to move downwards with the same velocity: And these weights being compared as two meeting each other with equal velocity, wherefore since the quantity of motion in the greater is 8 degrees, and in the second 4, and supposing them contrary to each other; the motion in the aggregate remaining is as 4. to be divided by 3; the velocity therefore in each will be as $1\frac{1}{3}$.

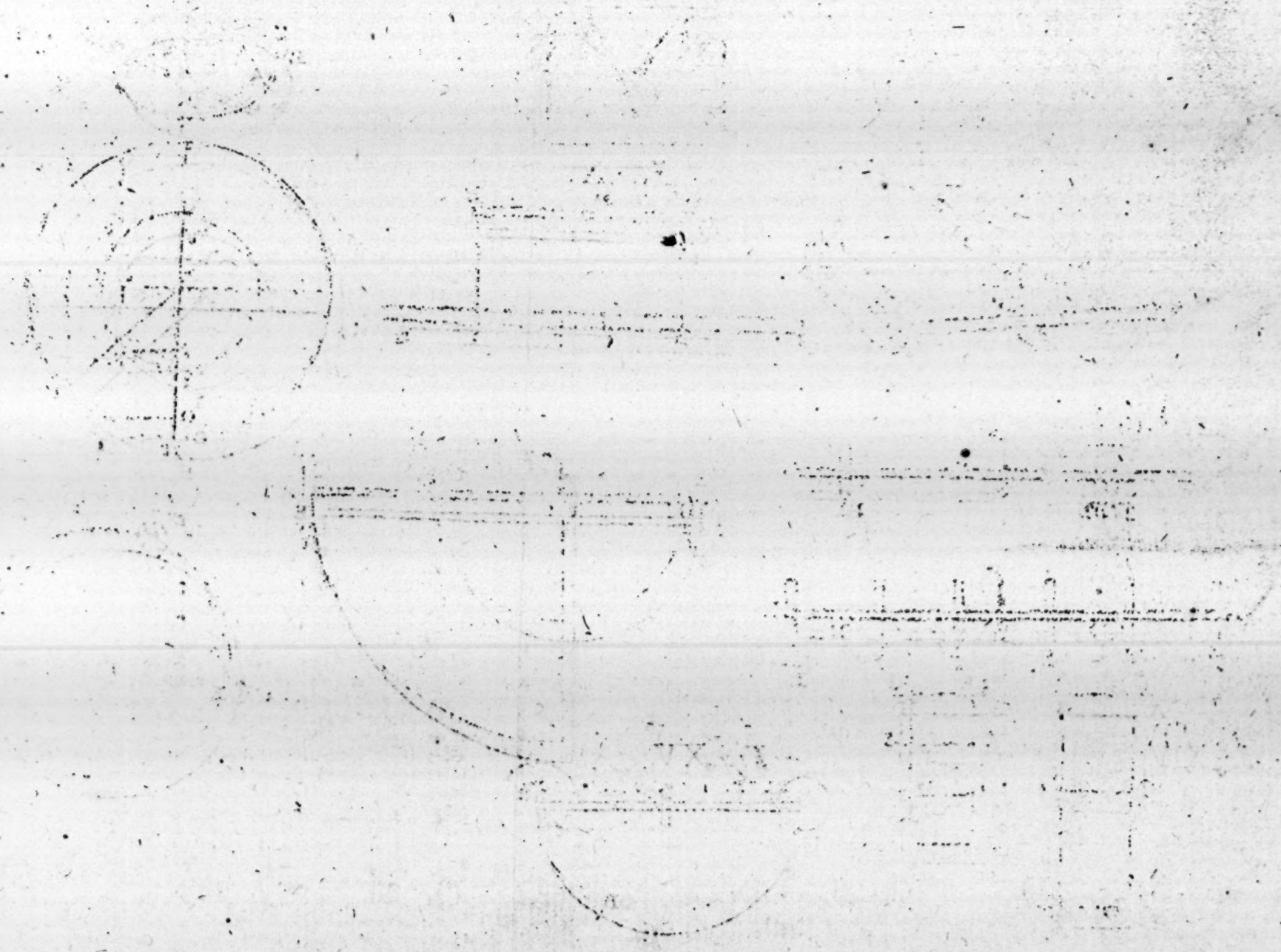
If there should be 2 equal *Pendulums* placed in two unequal Branches, the manner of reasoning will be the same. Suppose then the weights A and C to be equal, but the distance AD to be double the distance DC; in such disposition the velocity of the weight A will be double the velocity of the weight C, wherefore the quantity of motion in A will be double: Suppose the motion in A as 8, in C as 4, which motion since 'tis contrary destroys from the motion of the weight A, 4 parts, therefore there remains 4 parts to be divided, so that that of the weight A have 2 parts, and that of the weight C, 1 part, Therefore there are in A 2 parts and $\frac{2}{3}$; and in C 1 part and $\frac{1}{3}$.

PROPOS. VI.

Concerning the Proportion of weights, on the ends of the Arms of a Ballance, Variously placed from the Horizontal line.

Fig. 16. **T**He proportion of a weight in C to the same weight in F, will be as the whole Arm BC, to its part B μ , being placed between the Centre and the line of inclination F μ M, which the weight freely makes from the extrem F towards the Centre of the world. For the better understanding whereof, suppose on the other Arm of the ballance BD, and in the extrem D, a weight placed being less in weight than C, as B μ part of BC which is less than BD. It is clear from the 6 Proposition of the 1 book of *Archimedes* of weights, that if in the point μ you place the same weight C, the ballance





lance will little or nothing be moved from the *Horizontal* position. But if the weight F equal to C be placed in the extreame F of the arm BF ; it is the same as if it be placed in u of the *Horizontal* line Bu : To the better understanding whereof, Imagin a perpendicular thred Fu , and in its extreame u , the weight to hang which was at F , whence it clearly appears that it begets the same effect as when it was in F ; which as I said but now remaining fixt in the point u of the arm Bu , it is so much lighter than when it was in C , as uB is less than BC . I say the same, if the arm be posited in eB , which we may easily try if we hang thred from u of the arm BC perpendicular to e , in which extreame hang a weight equal to the weight C and at liberty from e of the Arm Be , whence the ballance will remain *Horizontal*. But if the arm Be be joyned in such site with the *Horizontal* BD , and the weight C be hung in e freely from a thred, it will neither ascend nor descend, which is only because it is hung by a thred which hangs as much from u , as that which is hanged freely from e of the arm Be ; and this proceeds from this, because it partly hangs from the Centre B : And if the Arm or Beam should be in the site BQ , the whole weight would remain hung in the Centre B , even as in the site BA the whole presses to the said Centre. Whence it comes to pass, that in this manner a weight is more or less heavy, by how much 'tis hung Farther from or nearer to the Centre; and this is the only Cause whereby one and the same weight in one, and the same mean becomes heavier or lighter. And although I call the side BC *Horizontal*, supposing it to make a right angle with CO , whence the angle CBQ becomes less than a right angle, by the quantity of an angle equal to that which is made by CO and BQ in the Centre of the Elementary region, yet this hinders nothing since the said angle is but of insensible Magnitude: From the same reasons we may conclude, that if the point u be equally in the middle between the Centre B and the extreame C ; the weight F or M will hang or incline according to the half of the said Centre B : And if the said u be nearer to B than to the point C , it will hang from it or incline to it more than the half; and if more towards C , it will be less than half.

PROPOS. VII.

How to know what quantity any weight or moving power hath in respect to another quantity, by Perpendiculars drawn from the Centre of the Ballance or beam to the line of Inclination.

Fig. 17. **F**ROM what has bin said 'tis easy to understand, that the quantity Bu which is almost perpendicular from the centre B in the 16 Fig. to the line of Inclination Fu , is that which hath led us into the knowledge of the quantity of the force of F in this site or position, to wit, the line Fu making with the arm Fb an acute angle BFu : Nevertheless for the better understanding whereof we will imagin in Fig. 17. the beam boa fixt in the Centre o at whose ends or extreames there is fixt or hung two weights, or two moving powers or forces e and c , yet so that the line of inclination e that is be make a right angle with ob in the point b ; and the line of inclination c that is ac makes an acute angle or an obtuse with oa in the point a . Imagin then the line ot perpendicular to the line of inclination ca , whence ot will be less than oa by the 18 Prop of 1 *El. of Euclid*: Moreover imagine oa to be cut in the point i , so that oi be equal to ot , and in the point i hang a weight equal to c , whose inclination make it a line parallel to the line of Inclination of the weight e , supposing nevertheless the weight or power c to be greater than e , in such proportion as bo is greater than ot ; without doubt by the 6th. Prop. of the 1st. Book of *Archimedes de equiponderantibus*, boi will not be moved from its site, but if in stead of oi we imagine ot made one with ob , and the power attracted by the line tc : c in like manner also will touch as bot according to common reason the site is not moved; therefore that which was proposed is done, also, hence we may easily note, how much vigor and force of weight or power c at a right angle with oa loses, drawing less: Hence also follows this Corolary, that by how much nearer the centre o of the ballance is to the
centre

centre of the elementary region, by so much also it will be lighter.

PROPOS. VIII.

From the two last Propositions all the causes of Ballances and Leavers depend. Fig. 18.

THe force of any arm of a ballance or Leaver that is long, is greater than a shorter, from the Preceeding propositions, that is, a weight placed on the end of the greater or longer arm, presses or endeavours more as it hangs more or less from the Centre.

Wherefore *Ballances* or *Leavers* are not purely *Mathematick* lines, but natural, and hence bodies exist conjoined with matter; now lets imagin ns to be a superficies which according to length cuts the Axis of a *Ballance*; and we will suppose its Centre first in i , and the greater arm to be iu , and the lesser in , and the *Vertical* line io , which let be so much as is the thickness of the *Ballance* from the upper to the lower side; for the better understanding whercof suppose ns a *Parallelogram*, and put two equal weights on the ends of the arms, experience teaches that the weight at us , is of more force than the weight at nx , and we would know the cause of this effect.

We have already said that *Ballances* or *Leavers* are of matter, and ns the medium of its superficies, suppose now i to be the Centre, which staies the said *Ballance* or *Leaver*; let us and nx be the lines of inclination of the weights, and we will imagin that the said weights hang from the points u and n , as indeed they do, although they should hang from s and x , because the point u and the point n are so conjoined with s and x , that he that draws one, draws the other also: Likewise we'el imagin the two lines iu , in , and ie which ie makes the angle oie equal to the angle oin ; Hence it appears clearly if we hang the weight u (which is equal to the weight n) at e , that hath plainly the same force as the weight n hath, and the *Beam* or *Ballance* will neither move up nor down, because both

both weights equally lean to the centre i , by the middle lines $e i$ and $n i$, but the said weight being placed in u , the line $u i$ by which the weight presses to the Centre, is more *Horizontal* than $e i$, and the line of inclination $u s$ is more distant from the Centre i than the line $e t$; whence the weight in this manner being also more free from the Centre i , results and is more ponderous than when it was in e , for the reasons mentioned in the two precedent propositions, and for this cause weighs up the weight placed in n . But if the Centre were in o and we imagin two lines $o s$ and $o x$, and suppose the weights placed in s and x , whence the line $o s$ will be more *Horizontal* than the line $o x$, and the line of inclination $u s$ will be more distant from the centre o than the line $e t$, its weight will also be heavier, because it hangs so much farther from the Centre o , and by reasoning as aforesaid we find the same effect to be true: In *Ballances* rightly and properly so called $x i s$ or $n o u$ may be *Horizontal*, but in all kinds of *Leavers* this only is said by a certain similitude; we may contemplate the same by supposing the Centre in the middle between o and i , which any one may easily do of himself without any other help.

Mechanick

Mechanick Powers.

OR, THE

Definitions of the *Leaver*.

BOOK II.

I. **A** *Leaver* is commonly a piece of a *Fir-pole*, or other Timber, about 6 feet in length, which we use either to raise or move heavy bodies, such as Timber or Stone, or any body of metal, or such like; wherein three points are assigned, first the power of the movent 2ly; Of the weight to be moved; 3ly, The prop, to which the *Leaver* is annexed, as to a Centre, describing two arches with a double motion.

2. Hence because these 3 points may be disposed three ways in this length, they produce 3 kinds of *Leavers*. First a *Leaver* of the first kind is that wherein the prop possesses the middle place, and the power and the weight possess the two ends, or extrems of the *Leaver*, as if the Power be in A, the Prop in B, and the weight in C.

Fig. 12. A *Leaver* of the second kind is that wherein the weight is placed in the middle, and the power and the Prop at the ends.

A *Leaver* of the third kind hath the power placed in the middle and the weight and the Prop at the two ends.

Before I enter on the Propositions, I shall premise some things worthy our animadversion.

Fig. 20. Suppose the *Leaver* to be os, u, x , whose *Prop* (or *Hypomoclion*) is in the point o , and the weight in the point n , 'tis clear that when you would raise it, it behoves also by the help of the hands to raise u ; now we must consider how the weight n endeavours towards u , and for this cause we will imagin the right lines no, ni, ne, nt , and nu , of which ni , is placed towards the Centre of the world, and nt makes an angle int equal to the angle ino : Now placing some power in i having equal inclination to the upper, as n has to the lower (setting aside the gravity of the *Leaver*) this power (according to common reason) will sustain the whole weight of the said n , and if the weight n were in x directly over o , the whole weight would be upon the *Prop*, and so much force or power of the *Prop* will suffice to resist for sustaining, as is the gravity of the weight; but putting it again in n 'tis clear that if another power be not opposed from the neither to the upper part of the *Leaver*, the *Prop* notwithstanding being excepted, it will behove the power of some part of the weight n (without consideration as aforesaid of the weight of the *Leaver's* matter or substance) that the *Leaver* be depressed from the part, s, u , and some one part of the weight n , because other part of the same weight endeavours it self to the *Prop* o , by means of the line on which makes not right angles with ox . But if from the point t this kind of resistance oppose it self that the *Leaver* be not depressed or born down, 'tis clear by common sence that the power of the weight n is divided equally in the middle, whose moiety over o resteth, as also the other over t being in the middle of the two lines no and nt . Now imagin the resistance t to be taken away and placed in e , it is clear also that the greater part of the weight n forces or endeavours to e by help of the line ne , more than to o ; since the line of inclination, ni , is nearer to e than o : Because all resistance either in i or in e , or in t or in n is instead of a centre as well as o , and the work of one helps tother; But if the same resistance be placed in u , 'tis clear also that a lesser part of the weight n , endeavours to u than to o ; since the said ni is farther distant from the centre u , than from the Centre o , and the proportion of the part of the weight n in o , to the proportion, of the part of the weight n in u will not be according to the proportion of the angles ni and oni , but according to the proportion of ui to io , which may clearly be comprehended by the converse of this effect,

effect, that is even, as now we have supposed o and u to be two Centres that sustain the weight e of n ; also imagin n to be a certain Centre from whence hang two weights o and u , so proportioned to each other, that ui and io are the certain causes of the ballance of these weights o s , which we call a *Leaver* or *Beam* inclined on no part: But returning to the proposition, we say, That the weight of n endeavoring less to u than to o , that is to t , there needs less force in u than in t to raise the weight n ; and so by consequence, the farther the point u is from t , the lesser force is required, and consequently when the force or resistance in u is so proportioned to that which is in o , as is oi to iu the *Leaver* or *Beam* will not be moved: But when there is a greater proportion of the resistance of u to that which is of o , than of that of oi to iu , then the part us of the *Leaver* or *Beam* will be elevated: But if the proportion be lesser than oi , to iu , than the *Beam* or *Leaver* will be depressed on the same part.

Of Augmenting Force or Power.

Fig. 21. **I**N some places Bakers use a certain instrument for kneading their Past, which is perform'd by one man only, which instrument seems worth our taking notice of, and 'tis thus: Imagine the plain in which he sets who kneads the Past, and in which the Past is laid to be TSD , and the triangle TAS fixed, and perpendicular to the superficies of the said plain; and in the Angle A joyn a piece of Wood or Leaver AE as a moveable semidiameter and equal to the Perpendicular of the Triangle, whence A will be the place of the centre, and DO will be the semidiameter which kneads the Past, and from its end O (which O when DO is Horizontal is found in the base of the said Triangle) comes the piece of wood OV , which with AV is equal to the perpendicular imagined from the angle A of the base TS playing too and fro in O and V , that the semidiameter DO may be raised and depressed. And VO is equal to AV , and V is in the middle between A and E , whence AV with OV are equal to AE ; moreover there are two pieces of wood perpendicular from

F

A

A, and fixt to the base and immovable; and so far distant from one another, that between them $O V$ and $D O$ may pass above and beneath, and not depart from the semidiameter $D O$. In the end of E there must be a small piece of Wood at right Angles with $A E$, which is held by the hands of some body which stands on the foresaid Machine, which man with that wood that is, the semidiameter $A E$ drawing it to himself from the superficies of the said Triangle, and then thrusting it towards the same Triangle, he excites the semidiameter $D O$ upon the Past with a great force.

In imitation whereof I have subscribed Fig: 22. $b a u x$, in which we may imagine u resembles A in the 21 Fig. and a denotes O , and $o V$, and $x E$: we may also imagine $u a$ to be the base of the Triangle $a u o$, to which $o t$ the perpendicular of the said base add $u a$; hitherto then $u o$ will be equal to $o x$, and to $o a$, we may imagine also $a o$ so-produced to b , that $o b$ be equal to $o a$. Also suppose a weight in a , to force towards u , whence the line of its inclination will be always $a u$; suppose also $a o b$ to be a Beam or Leaver, and o its Centre, whence the force or power of a will be proportional to $o t$, with respect to the force or power imagined in b , the inclination of the perpendicular $b a$, which force or power in b will be proportionable to $b o$ by Prop. 7. of this Treatise; therefore if you should place a certain power in b at a right Angle drawing the line $b o$ so proportionated to the power of the perpendicular a , as $o t$ is proportioned to $o b$, the Beam $b o a$ will not be moved, but any greater portion in b will overcome a : And when $o x$ is equal to $o b$, the same will happen according to common Sense, placing the power b in x . The quantity therefore of the power in x , which ought to overcome the resistance in a , which is put against u , ought to have a little greater proportion to resist, which in a makes a right Angle with $a o$, than that which is of $o t$ to $o x$.

Prop.

PROPOS. I. Fig. 19.

A Theorem.

IF in a Leaver, the Power be to the weight as the distance of each from the Prep, reciprocally, it will be in equilibrio, & the power will sustain the weight, but not raise it.

Suppose the power A to the weight C, to be as the distance BC to the distance AB; I say, it will be in *equilibrio*, and the power will sustain the weight C, but not overcome nor raise it; but to the better understanding of the Proposition, suppose the weight C to be 100 pounds, and the power A to be a power able to sustain 25 pounds without a leaver; and as the power A is equivalent precisely to a fourth part of the weight, so also the line BC must be a fourth part of the line AB to make it in *equilibrio*.

The Demonstration. The power is increased in the same proportion in which its motion is increased above the motion of the weight; but in such disposition the motion of the power is to the motion of the weight, as 4 to 1; for if the leaver be understood to be raised in L, so that the power describes the arch AL, the weight describes the arch KC; but the arches are alike, because the angles ABL, CBK are equal; or like arches opposite to the vertex, are as their Semidiameters, to wit, as AB to BC, and we suppose AB to be 4 times as much as BC; therefore in such disposition (by the first principle of this Treatise) the power A is quadruplicated, and therefore is equivalent to 100, but a power of 100 is in *equilibrio* with a weight of 100; therefore if as the power A to the weight C, so the distance CB to the distance AB, which is reciprocal, it will be in *equilibrio*, which was to be demonstrated.

PROPOS. II.

A Theorem.

IF the proportion of the Power to the weight be greater, than of the distance of the weight to the distance of the Power from the Prop, the power will raise the weight and overcome it.

Fig. 19. Let the proportion of the power A to the weight C be greater than of the distance BC to the distance AB; I say, The power A so disposed will overcome the weight C.

Demonstration. Suppose another power which hath the same proportion to the weight C, as the distance BC hath to the distance AB, this power will be in *equilibro* with the weight (by the precedent proposition) but the power A is greater than that power (by the 10th proposition of 5 *Euclid*). therefore the power A is greater than that which is in *equilibro* with the weight C, therefore it will overcome the weight C, and will raise it; which was to be demonstrated.

PROPOS. III.

A Theorem.

Fig. 23. **I**F the proportion of the distance of the Power from the Prop, to the distance of the weight from the Prop be greater than of the weight to the power, the weight will be overcome, and raised by the Power.

Suppose a greater proportion of AB to BC than of the weight C to the power A, I say the power will overcome the weight C.

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Fig. XVI.

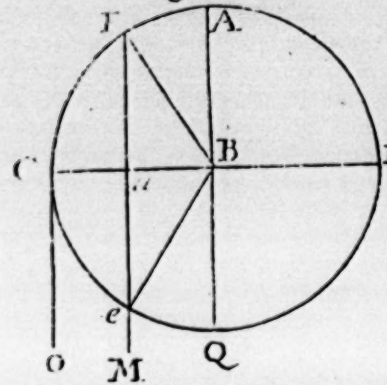


Fig. XVII.



Fig. XVIII.

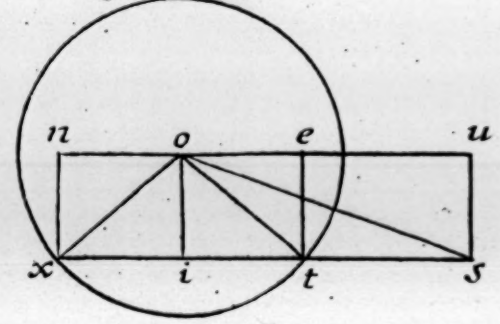


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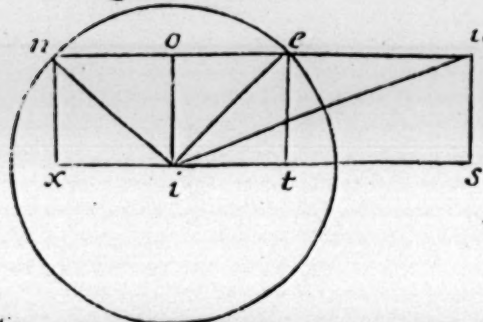


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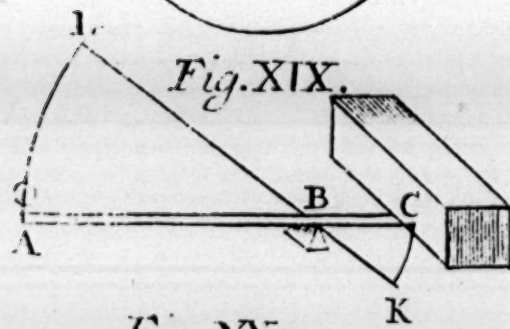


Fig. XX.

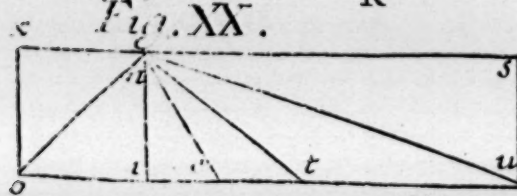


Fig. XXI.

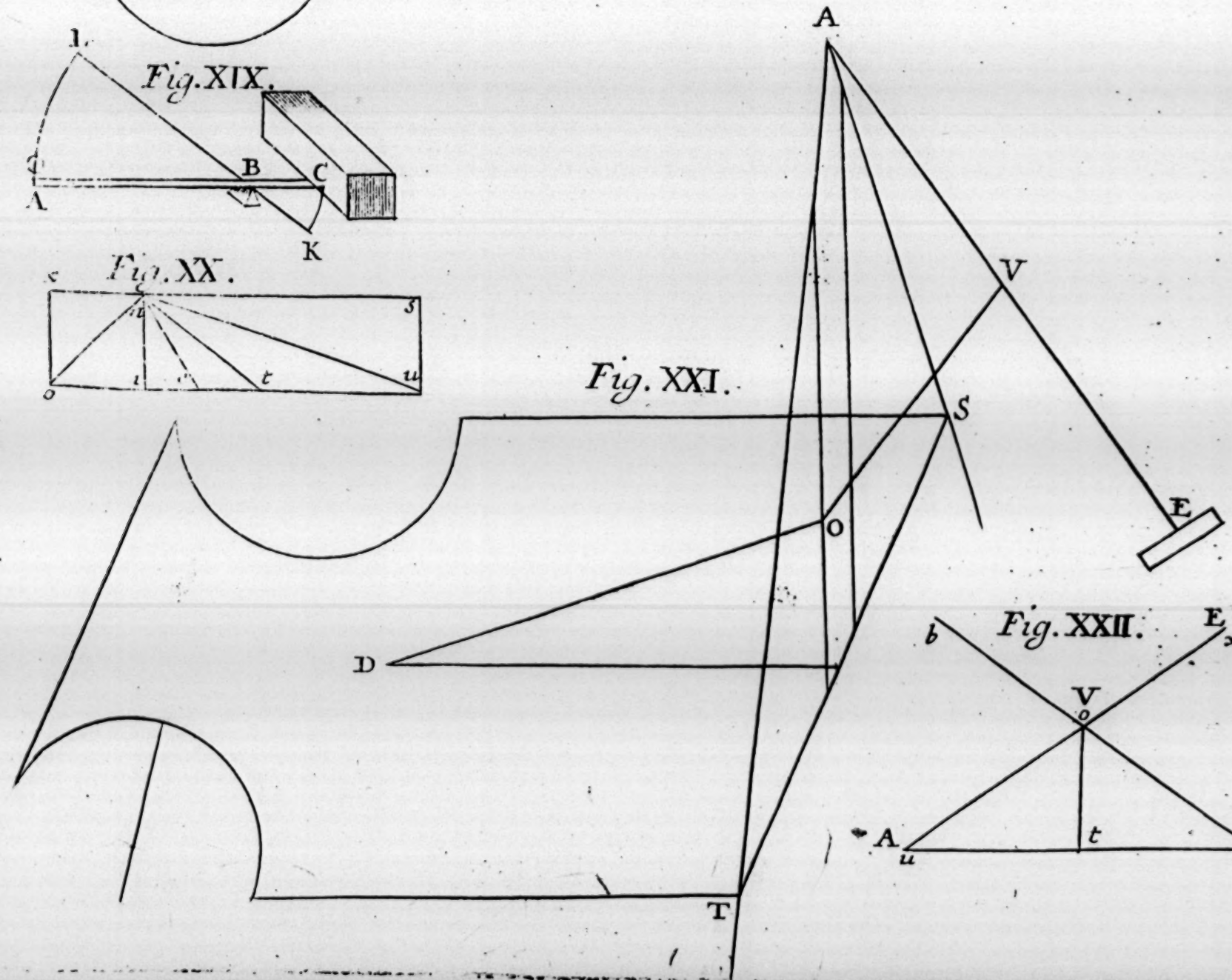
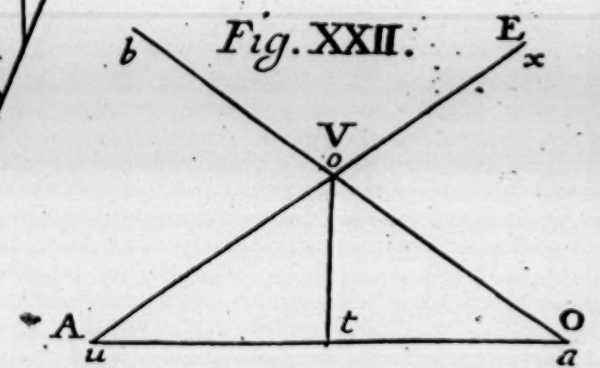
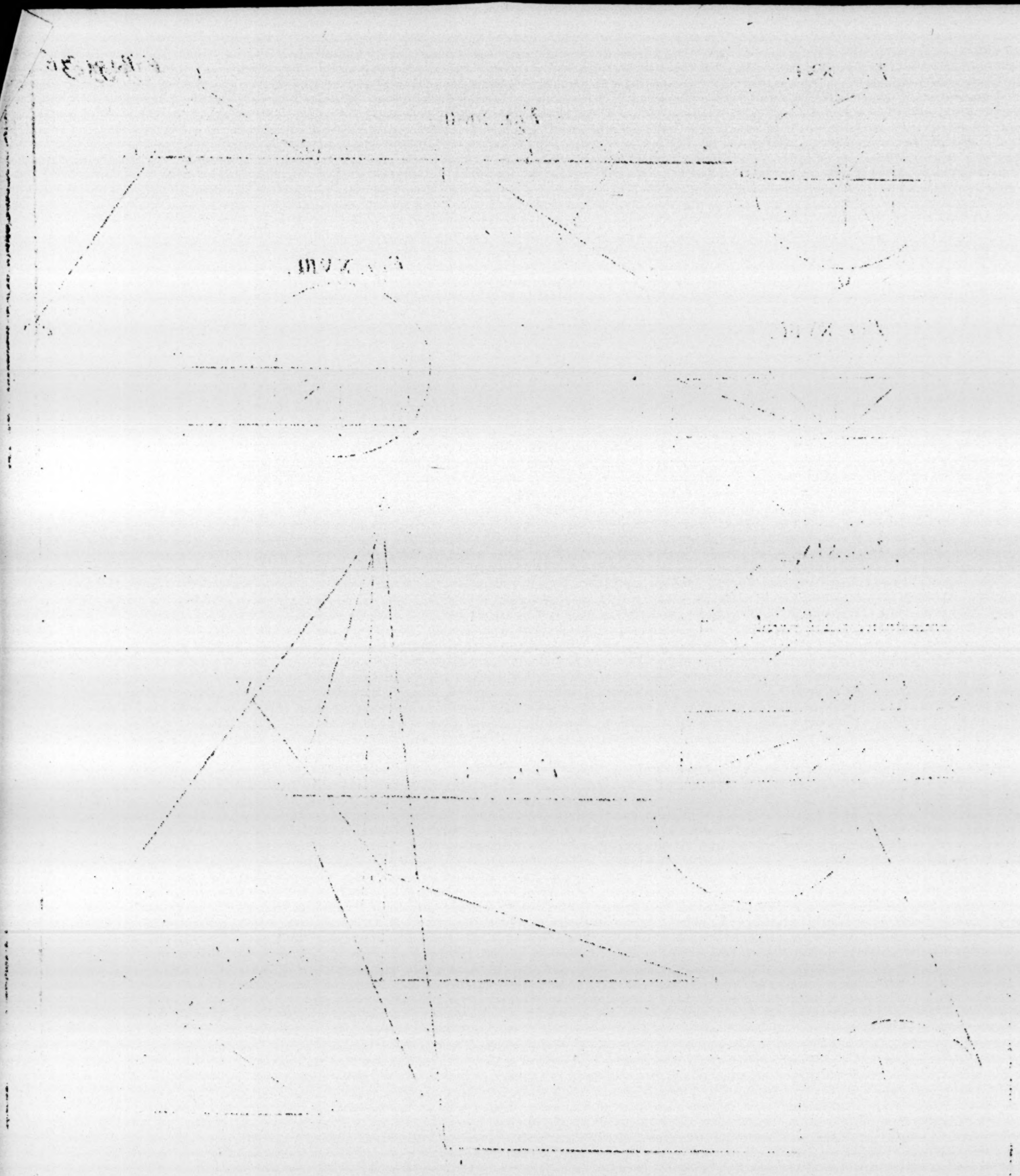


Fig. XXII.





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The Demonstration. Suppose another power D equal to A applied in the point D, so that as the weight C to the power D, so DB to BC (it will be by the 10th proposition of 5 *Euclid.*) DB less than AB, and (by the first of this) the power D applied in the point D will be in *equilibrio* with the weight C: But the power A equal to D if it be applied in the point A, hath greater motion with respect to the motion of the weight C; therefore by the first principle hath greater force than the power D which is in *equilibrio* with the weight C, wherefore that will overcome and raise it; which was to be demonstrated.

PROPOS. IV.

A Theorem. Fig. 23.

IF the proportion of the weight to the Power be greater than the distance of the power to the distance of the weight, or if the proportion of the distance of the weight to the distance of the Power be greater than of the power to the weight, the power will neither elevate nor sustain the weight.

First, Let the proportion of the weight C to the power A be greater than of the distance AB to BC; I say the power A is too little to make an *equilibrio* with the weight C; For suppose the power E to which the weight C hath the same proportion as AB to BC, and consequently the proportion of the weight C to the power E will be less than of the same weight C to the power A, and (by the 10th of 5 *Euclid.*) the power E is greater than the power A, but (by the first of this) the power E applied in the point A is in *equilibrio* with the weight C, therefore the power A is too little to be in *equilibrio* with the weight C; therefore can neither raise nor sustain it.

Secondly, Suppose the proportion of the distance BC to the distance AB to be greater than of the power A to the weight C; I say, The victory will be in the power of the weight C, for suppose the power E to be as BC to AB, so E to C, and the proportion of the power E to the weight C, will be greater than of the power A to the same weight C, and (by the 40th of 5 *Euclid.*)

5 *Euclid.*) the power of E will be greater than of A; but (by the first of this) the power E applied in the point A is in *equilibrium* with the weight C; therefore the power A is less than that which is applied in the same point of the Leaver, in *equilibrium* with the weight C, therefore the power A cannot sustain the weight C; which was to be demonstrated

Although in the Figure I have only put a leaver of the first kind, these proportions agree equally with the 3 kinds of Leavers, since in each kind as well the powers as the weights describe Circles.

PROPOS. V.

A Theorem.

A Power is equivalent to so many powers equal to it self in force, as its distance from the Prop contains the distance of the weight from the same.

Fig. 24. Suppose any power A fit to sustain without a Leaver, a weight of 100 pounds, so disposed in the Leaver that the distance of A from the Prop contains four times the distance BC of the weight from the same Prop or Centre; I say the same power in the point A is equivalent to 4 powers equal to it self in force, and so can sustain in this disposition of the Machine or Engin, a weight of 400 pounds.

The Demonstration. As many times as the distance AB contains the distance BC, so many times the motion of the power contains the motion of the weight, but (by the first principle of Machines) how much the motion of the power increases above the motion of the weight, it hath so much the more strength or force, therefore according to the proportion of AB to BC, the force of the power will be increased; but by supposition AB is four times as much as BC, therefore the power applied in the point A is equivalent to 4 powers equal to it self in vertue or force.

Or the power A equal to 100 pounds, will be equivalent to 4 powers equal to it self in vertue, if it sustains 400 pounds; and it can sustain them (by the first of this) if it be as the power

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power A to the weight of 400 pounds, so the distance BC to the distance AB, which plainly appears.

P R O P O S. VI.

The Power being placed the same distance from the Prop, and the weight being placed nearer to the Prop encreases the force of the Power.

Fig. 24. **F**IRST let the weight C be distance from the Prop B the distance of BC, and let the power be in A; I say if the power be always in the point A, and the weight be removed from the Prop B, suppose to the point E, that by how much the lesser BE is, by so much the greater will the force of the power be, in order to sustain or raise the weight placed in E; That is if the power applied in the point A can sustain or support a weight of 400 pounds placed in the point C; I say, If the weight C be removed from the Prop and placed in the point E; It will be as BE to BC so the weight of 400 pounds to that which the power A can sustain.

The Demonstration. For let it be as BE to BD so the weight C to the weight F; I say the weight F placed in the point E will be in equilibrio with the power A, for when 'tis as the power A to the weight C, so the distance BC to the distance AB; as also BE to BC, so the weight C to the weight F; Therefore from disorder'd equality (by 23 of 5 Euclid) the power A will be to the weight F as the distance BE to the distance AB, then (by the first of this) A and F will be in *equilibrio* which was to be demonstrated.

Corollary. I.

Fig. 25. From this Proposition arrives several practises which naturally or experimentally Workmen make use of for moving of weights, or overcoming the resistance of any bodies; And neither is this Doctrine only useful in raising and removing of heavy bodies, but also in cutting off bodies and parting them from each other, and overcoming any resistance, which I shall only shew in brief, that it may be turned from them to other matters.

First in digging Stones out of Quarries, they often use a Leaver or Croe of Iron, and when the Stone resists much, either by reason

reason of its greatness, or because it will not easily be seperated from the other to which it adhears, they remove the Prop as near to the weight as may be, that so they may move it the easier, and for the Prop they commonly make use of a Stone; or sometimes two Stones, as if the Stone EF were to be parted from the Stone DE , if DE be firm, the Prop will be in the point C , and the weight in B , and it will be a Leaver of the second kind and then the distance of the power will be the line AC , the distance of the weight will be BC ; then as many times as BC is in AC , so many powers equal to it self will the power placed in the point A be equivalent to.

But if the weight B be so drawn back from the body CE which the proportion of the Prop hath, that the distance CB be made greater, there may be put between those two bodies, some hard body, that so the distance CB may be lessened, and the force of the power more and more increased.

Fig. 26. In like manner when a Nail is to be drawn with a Hammer, by how much the Nail (which obtains the force of a weight) is nearer the Prop C , the easier it is drawn forth; whence when the Nail is drawn out a little way, so that the end of the Hammer C cannot rest on the Board or Timber that the Nail is in, we are wont to put another body between, that the distance may be less.

Fig. 27. In like manner in Pinchers is a double Leaver of the first kind, one whereof is the Prop, to wit, the Nail or Rivet B , about which each part is turned, and by how much lesser the distance BD is, and the distance AB or BC the greater, so much the more it strains.

Fig. 28. The same may be said of Shears, wherein this may be noted, The more they are opened the easier they operate; because that when they are more opened the body to be cut, is nearer the Prop B ; *Example*, Suppose it in D , but when they are shut farther, that which is to be cut, suppose it to be in the point E ; whence the proportion of the distance of the weight from the Prop is greater than the distance of the power from the same Prop or Centre; moreover the longer the Arms AB , CB are, the more the force of the power is encreast, and thus we see Workmens long Shears cuts any kind of Mettal; many other Instruments we might mention, which this principle easily discovers.

When

When we open a Lock with a Key, if it opens hard, we put a Stick into the ring of the Key and turn the Key with it, for by so doing we make use of a longer Leaver, than when we turn the Key with our hand upon it.

When we open Gates or Doors, if we lay hold of them further from the Hinges, they open easier than when we lay hold on them nearer to the hinges.

Also from this we may give a reason why a long Staff or Pike weighs more if it be lifted up by one end, than if nearer the middle; as also why a long Stick, or Staff; or piece of Timber, is bowed or broke with more ease than a shorter.

Hence likewise a reason may be rendred, Why in Mills some teeth are made stronger and nearer together than others, *viz.* the foremost; many things we may run through which may be reduced to the Leaver; as in Navigation, the governing or Steering a Vessel, rowing with Oars, &c.

PROPOS. VII.

A Problem.

To move any weight with any Power by a Leaver of the first and second kind.

Fig. 29. **L**ET there be given any weight B, and a power A, how little soever; I say the weight B may be moved by the power A, with a Leaver of the first or second kind; for since the weight B is not infinite, it will have some proportion to the power, therefore divide the Leaver CD, and make it, as the weight B to the power A: So the line CE to the line ED; suppose the Prop in the point E, and the weight applied in the point D, and the power A in the point C; I say it will be in *equilibrio*.

The Demonstration. For since the power A is to the weight B, as the distance ED, to wit, of the weight from the Prop, to the distance CE; to wit, of the power from the Prop (by

G

the

the first of this) it will be in *equilibrio*, but if the Prop be moved never so little to the weight, the power will overcome the weight and raise it.

We will do the same by a Leaver of the second kind, for make it, as B to A, so FH the length of the whole Leaver to GH, and let the Prop be at the end as at H, the power at the other end at F, and the weight in the point G, as yet (by the first of this) it will be in *equilibrio*; but if the weight be moved never so little to the Prop, the power will raise the weight, and overcome it.

But a Leaver of the third kind, we cannot use to effect the same thing, for when the weight is placed at one end, and the Prop at the other, the power which possesses the middle place will always be less distant from the Prop, than the weight will; and is so far from helping the Machine to encrease the force of the power, that it hinders it, and the weight from such disposition of the Machine increases its resistance; for generally speaking, as often as the disposition of the Machine increases the force of the power; so often, if the power and the weight change places, the force of the power is abated, and so much the resistance of the weight encreased.

And this is *Archimedes's* great Problem, That he would move the whole Globe of the Earth, if he could find but a place to fix a Prop upon, which in Speculation is true, but in practice impossible; for who can practically divide the length of a Leaver into any proportion, especially, if for Example, The Hundredth Thousand part of a Line were required, for it would make the distance of the weight so small from the Prop, that the seat of the Prop would be impossible to be distinguished from the distance of the weight.

P R O P O S.

 PROPOS. VIII.

A Problem.

To place a weight so on a Leaver, that no finite power, how great soever, can overcome it.

Fig. 30. **L**ET the weight A be never so little, and any power B equivalent to it, I say these may be so placed, that the power B, whatever it be, will be unable to raise the said weight. For suppose, as the power B to the weight A, so the distance KL to the distance LM, and the power B in the point K, and the weight A placed in M by (the first of this) it will be in *equilibro*; whence if the Prop L be removed never so little to the power consisting in K, it will be unable to raise the weight; also a Leaver given supposing the Prop thus, we may divide it, that a power being placed at one end, shall not raise the other end of the Leaver; *viz.* If we divide the Leaver KM, supposing the Prop L very nigh the power in the point K, it will come to pass that the power, though very heavy, will not raise the other part of the Leaver LM.

PROPOS. IX.

A Theorem.

Fig. 31. **W**HEN the Centre of gravity of a weight is in the line of the Leaver, the same force is always required to move it, whatsever site it obtains, so that the force move only downward or upward.

Those things which we have demonstrated concerning the Leaver, in the former Propositions are more universal; nor do they shew divers Circumstances worthy of Note, which here we ought to examine; And certain it is that a living power which is often used with a Leaver, since 'tis indifferent to all motion, it will move as well downward as a thwart. But weights which by their own nature gravitate only, resist motion upwards, and therefore their circular motion is not so much to be considered, as their simple Perpendicular motion, which, that I may handle every one severally, I shall expose several Cases. And First, we shall take notice of the power forcing only downwards as it were, and so a weight may be compared in divers manners with a Leaver, for either the Centre of gravity of the weight, or as it were its middle is in the Leaver, and which is the same, is hanged freely on the Leaver, or it is above the Leaver, or beneath the Leaver: In this proportion we appoint the Centre of gravity in the Leaver.

Suppose the Centre of gravity of the weight A in the Leaver; I say, If the power only force downwards, the same power is required to sustain the weight in what site so ever it is.

The Demonstration. As well the weight as the power tend downwards, wherefore if the circular motion be considered, both of the power and the weight, they will be proportionally distant, or their distances will be proportional, since like arches are proportional to the Semidiameters of their Circles; or if the perpendicular motions G E, C H be considered, they also will be proportional, because the Triangles C B H, B G E are proportionals; whence if the power move only downwards, the same force is required to sustain or move the weight, whether the Leaver be *Horizontal* or *oblique*.

PRO-

 PROPOS. X.

Fig. 32. **A** Power moving equally in every different place, moveth a weight more easily, whose Centre is in an oblique beam or leaver, than in an Horizontal one.

Let the power be A, equally able to move a weight in any difference of place, and let the weight be D, whose Centre is in the Leaver; I say, If the Leaver be raised in E, the power will more easily move the same weight, than if the Leaver were Horizontal, as A D.

The Demonstration. Weight, or any heavy body, resists only motion upwards, therefore a Perpendicular line is its measure of resistance; Therefore, First let the weight be moved according to the Arch DE, the resistance will be the line EH, Secondly, let it be moved according to the other Arch equal to EF, the resistance will be according to the Perpendicular FI; And it is clear, that the line FI is less than the line EH: Therefore although the same power move through the Arch CB, equal to AB, and so advances the same vertue or force (according to the first principal) you will find less resistance in E than in D, therefore it will move easier while the Leaver obtains an oblique site or position, than when it hath an Horizontal; which was to be demonstrated.

Corollary.

Hence it follows, That in an oblique site a power is in equilibrio with a weight, although the proportion of the power to the weight be not reciprocally the same, which the distance of the weight is to the distance of the power from the Prop; to wit, because the motion of the weight, according to which its resistance endeavours, is not the Arch EF but the Perpendicular line FI, although the motion of the power, according to which it exercises its activity should be by the Arch BC, but the Arch BC and the Perpendicular FI are not proportional to the distances KB, KE.

Nevertheless

Nevertheless in an *Horizontal* site DA, because the Perpendicular Phisically falls in with the Circle DH, the common Rules ought to be observed.

PROPOS. XI.

A Theorem.

Fig. 33. **I**F the Centre of a weight be above the Leaver, the weight is easier raised above the Horizontal line than beneath, from the power only forcing downwards.

Suppose the weight A, and its Centre above the Leaver; since the weight always presses downwards according to a Perpendicular line; in an elevated site it weighs downwards according to the line IF; and then the true distance will be the line FE; but in an *Horizontal* site the true distance will be BE: In a depressed site it will be DE; 'Tis certain, that DE is greater than BE, and this greater than FE, and so in respect of the power applied in the Leaver, and only pressing downwards, the motion in C will be more difficult than in A, and in A than in I.

But what I have said is with respect to the power, its moving simply downwards; because if it should move equally, or alike in every different place, the proportion of the Doctrine delivered in the 10th Prop. would ensue.

PROPOS. XII.

A Theorem.

Fig. 34. **W**Hen a weight hath its Centre of gravity beneath the Leaver in a depressed site or Position, less force is required than in an Horizontal, and greater in an elevated site.

Supposing

Supposing the Proof of the former Proposition, this appears clear enough, neither doth it need any further explanation, since in a depressed site the Perpendicular cuts off a lesser or shorter distance than in the *Horizontal*, and in an elevated site it cuts off a greater; the same caution is to be noted.

But when the weight freely depends on the Leaver, it is almost in the same manner, as if the Centre of gravity of the weight were found in the Leaver: For always the same distance remains to the Prop or Centre, especially virtually, because the weight so moved, is as if it truly existed in that point of the Leaver whereby 'tis hung.

P R O P O S. XIII.

A Theorem.

Fig. 35. **I**F by reason of the Figure of the Prop, the point on which the Leaver rests be changed, the proportion also of the force of the Power, to the resistance of the weight will be changed.

The Figure of the Prop. may be various, and it may be so made, that in its motion it may bear the force of one or another point of the Leaver; whence it comes to pass, that the distance of both the power and the weight are not the same; and so the whole proportion of the force of the power to the resistance of the weight is changed; as if the Prop. should be Sphærical, and the Leaver in an *Horizontal* site should touch it in the point A, but in an elevated site it would touch it in the point B; The same I say if the Prop. should be an oblong.

P R O P O S.

 PROPOS. XIV.

The motion of a power oblique to the Leaver, is less powerful than when right.

Fig. 36. **I**F the power be A, which presses the Leaver according to the oblique line A B; I say this motion is less powerful or able, than if the same force prest the leaver according to the perpendicular line A C.

The Demonstration. That motion tends not so much in raising the weight, as in drawing back the leaver from the Prop, as the motion A D forces the leaver against the Prop, and consequently it rather resists the Prop. than the weight.

PROPOS. XV.

A Theorem.

A motion so pressing forward to the weight, that it forces it obliquely to the line, according to which it should be moved, is less powerful.

Fig. 37. **T**HE weight is A, which should only move according to the line A B, and the Leaver whose Prop is in C, touching the weight in the point D, and forcing it according to the line D E; I say, The motion of such weight will be more difficult than if it had been forced according to the line A B; for the force of motion according to the line D E, as composed of a double motion, to wit, as it were of a Perpendicular, and of an *Horizontal*; I say; as often as 'tis Perpendicular, it resists the subjected plane, and so part of that force is used in vain, in overcoming this resistance.

Prop.

PROPOS. XVI.

A Theorem.

WHen two Powers consisting at the ends of a Leaver, sustain a weight hung on it, that which is neereſt to the weight ſuſtains the greater part of the weight, and that which is further, the leſſer part proportionally to the diſtances reciprocally.

Fig. 38. There are two powers A and B conſiſting at the ends of the Leaver, and ſuſtaining the ſame weight C; I ſay, the Power A ſuſtains a greater part of the weight than B; that is, if the weight C be 60 pounds and B C the double of A C; I ſay, the power A ſuſtains 40 pounds, of the weight, and the power B ſuſtains only 20 pounds: Or that the powers may ſuſtain the weight C, the power in B muſt be equal to a weight of 20 pounds, and the Power in A equal to 40 pounds.

The Demonſtration. The Power A in reſpect of the Power B is as the Prop, therefore that they may be in *equilibrio*, it ought to be as, A C, the diſtance of the weight from the Prop A, to A B the diſtance of the power from the ſame Prop, ſo the power B to the weight C reciprocally (by the firſt of this) but A C is by ſuppoſition a third part of the line A B, therefore there is required in B a power equal to a third part of the weight, to wit, of 20 pounds; In like manner, becauſe with reſpect to the power A, as the power B hath by means of the Prop, ſo will be the diſtance C B of the weight from the Prop, to A B the diſtance of the power from the ſame, as the power A to the weight C reciprocally, (by the firſt of this) but C B is ſuppoſed to contain two third parts of the whole line A B, therefore alſo the Power A will be equal to $\frac{2}{3}$ parts of the weight C, to wit, of forty pounds: Which was to be demonſtrated.

Corollary. I.

If the weight be precisely in the middle, each power sustains only an half part.

Corollary. II.

Both Powers taken together, ought to be equal to that power which can raise the weight without a Leaver.

Corollary. III.

Hence we may determine whether the Prop be fit to sustain the weight, for it always agrees with some part of the weight, especially in Leavers of the second kind.

Corollary. IV.

In a Leaver of the first kind, the Prop sustains as much of the weight as the power, and its resistance ought to be equal to both taken together.

Corollary. V.

When 2. powers consist at the ends of a Leaver sustaining a weight placed in the middle, we may easily determine how much of that weight each power bears, to wit, by dividing the whole weight according to the proportion, which the powers have with the weight reciprocally; What I have said in respect of the Leavers bearing or sustaining the weight, may also be understood of drawing a weight; As if 2. draw, and the weight A be fixt; not in the middle of the Leaver B.C; the Leaver will be moveable only about the point D.

PROPOS.

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Fig. 40.

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PROPOS. XVII.

A Theorem.

Powers consisting at the ends of a Leaver, do not bear the weight easier on a longer Leaver than in a shorter.

Fig. 39. Let the powers be A and B, and the Leaver likewise A B, sustaining the weight C; and let there be 2 other powers D and E sustaining the same weight, or one equal to it, on the longer Leaver; I say the length of the Leaver D E adds nothing to the facility; for let there be the same proportion of A C to C B, as of D F to F E, I will shew in both cases that the same part of the weight is sustained by the power B, as is sustained by the power E, and the same by the power A as by the power D: In like manner (from *Corollary 2*) I will shew in both cases that the powers taken together are equal to the weight, whence the greater Leaver effects no more than the lesser.

Neither doth it seem strange, that the length of the Leaver adds nothing to the force, that is, if two Leavers of unequal length, but divided alike from the Prop, that is, let the proportion of the distance in both be a like, the like effect follows in both.

PROPOS. XVIII.

A Theorem.

While 2 Powers sustain a weight, whose Centre is above the Leaver, in a declined site, the lower Power bears the greater weight.

Fig. 40. Let the 2 Powers be A and B, and let the weight be above the Leaver and its centre C, and let the perpendicular

cular be CD : I say, the power B sustains greater part of the weight than if the Leaver were in an Horizontal site; For the weight always acts by a line perpendicular to the Horizon, as in this case by the line CE , when before it acted by CD , therefore the weight becomes nearer the power B : wherefore the power B bears a greater part of the weight (by the precedent.)

But if the weight be beneath the Leaver, the contrary happens, as in the second example, in which the weight hangs on the Leaver by the line IK , which weight inclines to the power F , and therefore in this case, the power F bears more weight, than if the Leaver were in an *Horizontal* site; Lastly, if the weight hang freely it will not change the site. and consequently, neither power suffers by the declination of the *Leaver* or *Beam*.

PROPOS. XIX.

A Theorem.

WHEN a power draws by a line oblique to the Leaver, its true distance is a perpendicular from the Prop, to the line of Direction.

Fig. 41. Let the Leaver or Beam be AB , and the power drawing by the line BC oblique to the Beam, to which from the Prop F is drawn a perpendicular FD ; I say, the true distance of the power to be look'd upon, according as the increase or decrease of the vertue, or force, is the line FD .

The Demonstration. Suppose the power to consist in the point D , which draws the cord from D in E , and draw the line FE ; In the mean time the Leaver descends in the point G draw the line EG , and because in the triangles FDB , FEG , the sides FG , FB , also FD , FE , and the length of the Chords BD , GE is the same (by the 8th of the 1st. of *Euclid*.) all the angles will be equal, among which GFD , BFE will be equal, and the common angle BFD being taken away, there remains the angles GFE , DFB equal, and consequently the arches BG ,
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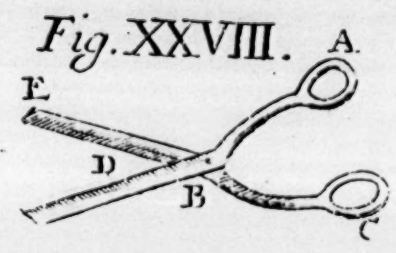
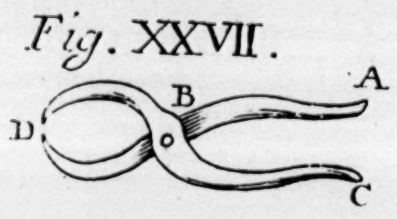
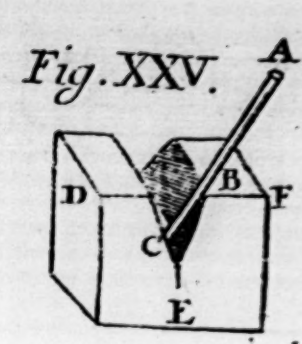
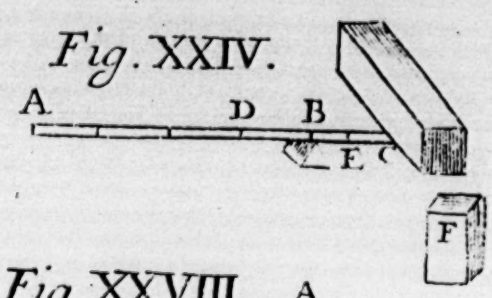
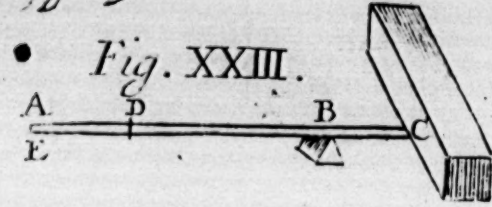
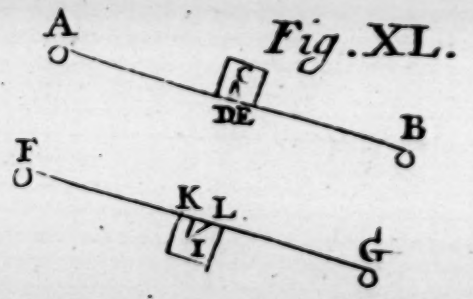
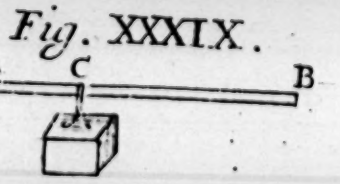
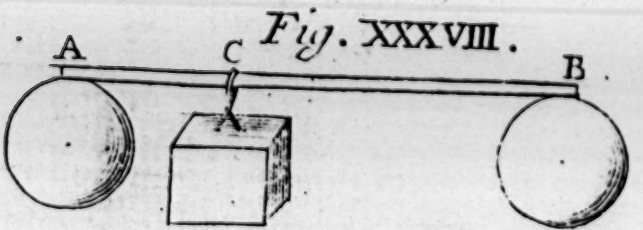
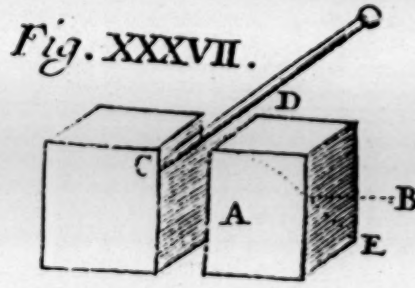
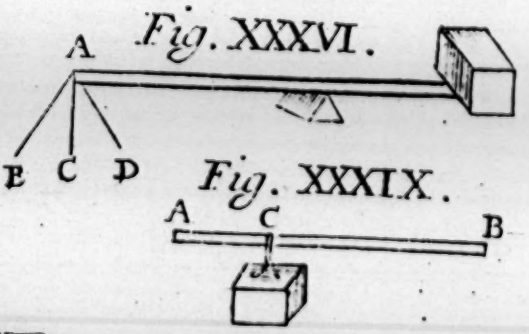
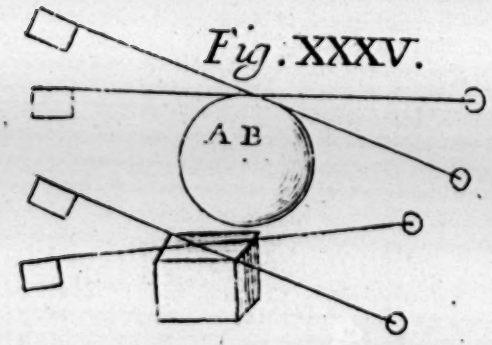
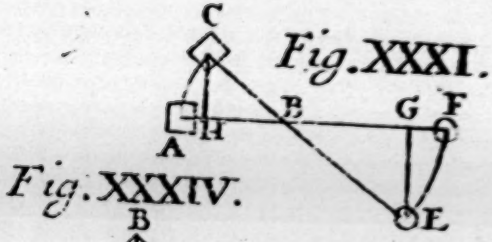
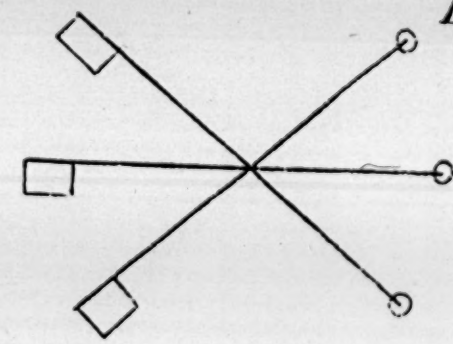
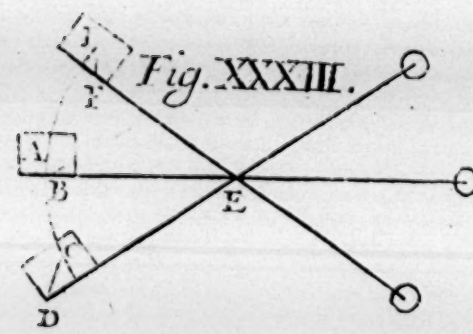
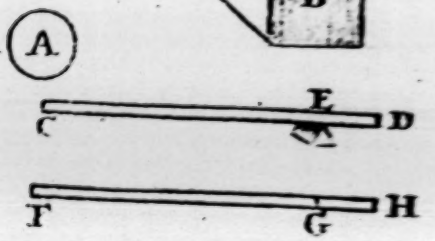
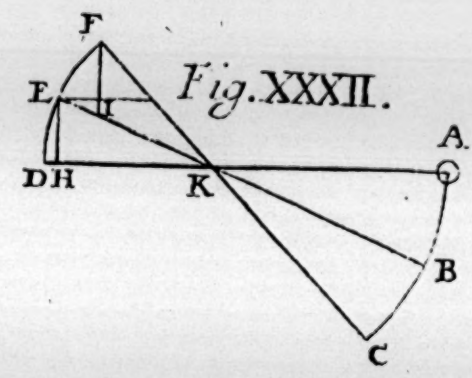
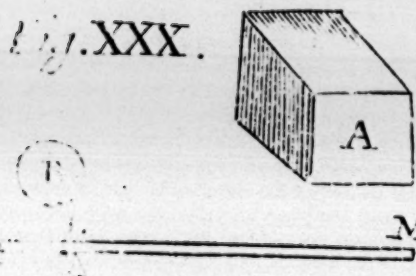


Fig. XXIX.



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HI equal. But the arch DE according to which the power is moved, is to HI or BG, or AK the motion of the weight, as FD to AF: therefore the true distance, according to which the motion of the power encreases or decreases in is the line FD, perpendicular to the line of direction; which was to be demonstrated.

But if the power be in the point C, and it move upon the Circumference MC, it may easily be shewn that the arch MC, is equal to the arch BG, and consequently in this case the true distance seems according to that which is lookt upon as its force, to be the line FG or FC, which would be contrary to the precedent part of the proposition: But the line BC is supposed to be flexible in the point G, and so the power placed in C may move about the point B, as about a Centre, although the Leaver FG remain unmoved. Supposing then from the point B, as from a Centre, we describe the arch CO, so that the line BO, which may be imagined, be equal to the line BC; draw a chord from the point O even to M, so that in the mean while the end of the Beam pass from the point B, to the point G, and OM will be the true motion of the power, which I affirm to be equal to the line DE; For since DC or DO is one half part of the line CK, and EM half of the line MG; then DO and EM will be equal, and that which is common being taken away, *viz.* EO, then DE and MO will be equal, wherefore the power in on that end of the line is not more moved than if it were applied in the point D, therefore its true distance will be FD; which was to be demonstrated.

Corollary. I.

If the line BC be not Flexible, neither in the point B nor any other, but firmly adheres to the point B, the thing will be otherwise; for if you apply the power in the point D, its distance according to what is examined of the increase or decrease of the force, will be DF, but if it be applied in the point C, its true distance will be the line FC, and its true motion, according to which it moves, will not be only the line MO, but the whole arch MC.

Corollary.

Corollary. II.

Fig. 42. The line of direction which is perpendicular to the Leaver is most apt to move, and by it the power hath the greatest force that it can have at the end of the Leaver; for let the Leaver be AB , the Prop C , and let the line of direction BD be perpendicular to the Leaver AB : I say, in any other line of direction, the power is less able; for let it be another line BE , which makes an accute angle CBE , and which consequently falls within the circle, draw to it the perpendicular CF , which (by the present) is the true distance of the power, and less than CB , wherefore when the Leaver draws by the line BE , it hath less force than by the line BD . Moreover let there be another line of direction BG , and the angle CBG obtuse, and consequently the other angle CBH will be accute, and BH will be within the circle which being divided in the middle in I , (by 3 of 3 of *Euclid.*) CI will be perpendicular to BH , and the same CI will be the true distance of the power; which since 'tis less than CB , the power also will have less force.

Corollary. III.

Fig. 43. The true distance of weights which draw by gravity only, is a Segment of the Leaver *Horizontally* placed between the Prop and the perpendicular; let the Leaver be AB , the weight by its gravity drawing downwards in B : Suppose the line EF in an *Horizontal* site, and draw the perpendicular BC ; I say, the true distance of the weight B is DC , for all heavy things draws by a vertical line to which the *Horizontal* line DC is perpendicular; I say, the same if the weight were in the point H , the true distance would be DG . Whence it follows, that a weight depending on a Leaver *Horizontally* disposed hath greater force.

And here I will add something out of the Learned *Casatus* his *Mechanics*; says he It may perchance be pertinent to our present purpose, and not unpleasant to the Reader, if I here declare something of an invention: When I heard a certain man, declairing that a Bell of a vast weight, was carried easily on Brass Wheels, which by length of time were worn out, but by

by what artifice, or in what order they were disposed, or made, he could not tell; Wherefore he considering with me how it might be done, I happened on this thought, that I esteemed the most heavy bell, might easily be repulled, by diminishing, or lessening the resistance, which arises from the wearing of the Prop, or Stay, and Axis together; For let B and C be two small wheels (Fig. 44.) of solid Brass, whose diameters are in some different proportion to the diameter of the axis on which the bell bears, or lies; And let the semidiameter of the Axis be A E, and of the little Wheels B E, in proportion double, therefore also the peripheries will be in the same proportion, therefore while the point I in H compleats a quadrant, the little Wheel also is turned about, whose periphery is equal to half a quadrant; Wherefore if to the little Wheel there should be fixt an Axis, whose Semidiameter B G is equal to the Semidiameter A E, the rubbing or wearing will be made with $\frac{1}{8}$ part of the Periphery of the Axis of the little wheel B; but because also in the little wheel C, the rubbing or wearing, will be made equal with the same Axis, almost nothing of moment is gained, because the whole wearing is equal, as if the quadrant E O were turned about in a firm and hollow Prop: And it will rather be a lessening of labour in carrying the bell, if the little Wheels were fixed to an Axis: and since the Axis is *Cylindrical*, the subjected Wheels doubtless will touch in a line, a small part of the Prop; And the Axis of the Wheels suit or fit with their concave parts in the superficies which are worn while the wheels are turn'd round: Unless by chance the *Convex* superficies of the *Cylindrical* Axis B G, be somewhat lesser than the concave superficies of the Wheel; and therefore they touch each other according to a line as (by the 13th of the 3d. of *Euclid.*), 'tis easy to demonstrate, which doth not often happen.

But 'tis not needful to make such solid Axes to the Wheels B and C, For if the axis A E is convenient to bear the weight of the whole bell, a pair of equal Axes will resist or bear double the weight: Therefore 'tis sufficient if each of the Axes B and C, sustain half the weight; But since the resistance of the *Cylinders*, least they be broken, ought to be in triple proportion of their diameters, 'tis sufficient to find two mean continual proportionals between the semidiameter A E and its half; for that which is next less to A E will be sufficient, for the Semidiameter of a *Cylinder* having Subduple Solidity and resistance;

ance, but still the Semidiameter requires to be less, because the weight bears or presses obliquely on the Axes of the Wheels B and C; whence the weight of the bell on those axes is according to the lines A B, A C, and not according to the perpendicular A D. Therefore as A D to A B, so reciprocally the weight on A B to the weight on A D; but the weight on either axis is as the subduple (or half) Summ to the whole weight; therefore the weight on B A is less than subduple, and the proportion continuing is made less; For when the Semidiameters A E and B E are given, the whole B A is known; and B D, and also its equal B E is known; therefore (by the 47th. of 1st. of *Euclid*.) also A D will be known, whose quadrate you will find, if from the Square of B A you subtract the Square of B D.

Therefore if by *Hypothesis*, B A, be 3, its Square is 9; and B D 2, its Square is 4, which subtracted from 9, there remains the quadrate 5, whose root is 2,23 and is the right line D A: The weight therefore on B A to the whole weight of the Bell on both axes B and C, is as 2, 23 to 6,00: But because the resistance of like solids is in triplicate proportion of their homologal sides (and in *Cylinders* the proportion of their diameters is had) if you seek two mean proportional numbers between 6, 00 and 2, 23 which you may do if you draw the quadrate of one extream into the other extream, for the Cube root of the product is the term next to that number whose square you assumed: Therefore first, the Square of 6, 00 being 36, 0000, draw it into 2, 23 and the cube root of the product 80280000 is 431, $\frac{1}{3}$: But the quadrate of the other extream 2, 23 is 49729 being drawn into 6, 00, gives 29837400 whose cube root 310, is the other mean; Therefore the 4 numbers 600, 431 $\frac{1}{3}$, 310, 223, are continual proportionals, the fractions being slighted; Wherefore if you make it as 600 to 431, so the semidiameter A E to B N; this semidiameter sought will be sufficient to bear the weight.

And because B E is the double of A E, and A E to B N is made as 600 to 431, B E will be to B N, as 1200 to 431; And according to this same proportion will the Semiquadrants be that are described by them. But the eighth part of the *Periphery* from the radius B E, is equal to the quadrant from the radius A E; therefore the quadrant E O to the Semiquadrant of the radius B N, is also as 1200, to 431, Therefore if the rubbing upon of the axis of the bell with the fixed Prop and hole, be 1200, the

Fig. 45.

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the Wheel B with its Axis is 431, to which the rubbing upon of the other Wheel C with its Axis is equal; and therefore the under Wheels the diameter whereof is only double to the diameter of the axis of the bell, the rubbing upon is as 862 to the rubbing upon which is as 1200; If therefore the diameter of the Wheels to the Axis of the bell be not only double, but triple or quadruple, the rubbing upon will be much lesser, and the facility in carrying the bell greater.

Mechanick-Powers.

OF, THE

Wheel or Axes in *Peritrochio*.

BOOK III.

Fig. 45, 46. **A**Xes in *Peritrochio*, which in Latin they call *Suculum*, or *Windlace*; It consists of a *Cylinder*, or round piece A B, to which is fixt an Axis C D, it hath also handles or radius's fixt to the *Cylinder*; about the *Cylinder* a rope is turned to which the weight is fastned; sometimes the Axis C D, is parrallel to the Horizon, as in Fig. 46, and sometimes it is perpendicular to the Horizon, as in Fig. 45. and may be variously made, and yet its essence; or being, remain unchangeable, and the same power persevering in augmenting; For whether the handles be immediately fixt to the *Cylinder*, as in Fig. 46, or whether they be fixt to the Circumference of the Wheel, as in Fig. 45. it differs little, for the true length of the radius is the distance of its end from the Axes.

PROPOS. I.

A Theorem.

THe Wheel or Axis in Peritrochio, is a Ballance or Leaver.

Fig. 47. Let the base of the Cylinder be A B, its Centre, or the Common Section of the base and Axis the point C, which when 't is immovable hath the force of a fulciment or Prop, let the weight hang from the point A, and the Power in D, I say there will be found a *Ballance* or *Leaver* of the first kind, for although the handle B D be not always fixt in the same plain wherein the weight A is found, nevertheless it describes an equal Circle to that which it runs over, if it exist in the same plain; and therefore is found to be a *Ballance* or *Leaver* of the first kind, And the same Propositions which we have made of the *Leaver* may be applied to this Engin, since the increase of the motion of a power above the motion of a weight is the same; Therefore (by the first principle of this) the increase of force is the same: But in the second case in which the weight depends on the point F, the Prop is in H, and the Power in G, 'tis a *Leaver* of the second kind.

But if the power be in the point K, the Prop in L, and the weight depend on the point M, as yet it will be found a *Leaver* of the first kind, but being thus disposed, the force of the Power is diminished.

Lastly, If the *Fulciment* or *Prop* be in the point O, the Power in P, the weight in R, it will be found a *Leaver* of the third kind, wherein the force of the weight is increased, and the force of the Power lessened; notwithstanding, this disposition is not unuseful when the power exceeds the weight by a longer interval or space.

Corollary.

Corollary. I.

If the Power be to the weight, as the Semidiameter of the *Cylinder* to the length of the handle, or radius, the power in such disposition will be in *Equilibrio* with the weight: And I suppose the Power to be applied in the extream or end of the radius, and to force the handle always perpendicular; The reason is clear, because (by the first Principle of this) 'tis then in *Equilibrio*, when the Power is to the weight, as the motion of the weight to the motion of the Power reciprocally. But the motion of the weight is to the motion of the Power, as its distance from the Axis, to the distance of the power from the same Axis: For while the power absolves one circle about the Axis, the rope also is once turned about the *Cylinder*, and the weight absolves an equal motion to one circumvolution, or one circle of the *Cylinder*, but Circles are to each other as are their Radius's, Therefore if the Semidiameter of the *Cylinder* be to the length of the handle, as the power to the weight, it will be in *equilibrio*, and the power will sustain the weight; which was to be demonstrated.

But that the force of this *Engin* may be the better concieved, take the Semidiameter of the *Cylinder*, and compare it with the length of the handle, which take from the Axis to the point in which the power is applied; and as often as the Semidiameter of the *Cylinder* is found in the length of the handle, so often is the power multiplied; that is, let there be a man in *Equilibrio* with 100 pounds, and let the Semidiameter of the *Cylinder* be 10 times found in the handle; I say, the same man can with this *Engin* sustain 1000 pounds.

Corollary. II.

But if there be a greater proportion of the power to the weight, than of the Semidiameter of the *Cylinder* to the length of the handle, the Power will raise the weight; for greater force is required to move a weight, and to overcome its resistance, than to make it even, or level.

In like manner if there be greater proportion of the length of the handle to the Semidiameter of the *Cylinder*, than of the weight to the Power, the power will be superior to the weight, and overcome its resistance.

Corollary. III.

If the power move the handle by a line, not perpendicular to the same; Its true distance from the Axes or Prop will be lesser: As if in *Fig. 48.* the handle be *BC*, and the power draws by the oblique line *CE*; the true distance of the power according to which we ought to measure its increase or augmentation will be the perpendicular *BD* (as is shewn at Proposition 19. of a *Ballance* or *Leaver*.)

Corollary. IV.

If a rope be so turned about a *Cylinder* that it makes the folding spiral, or that one Spiral folds on another, it makes the difficulty of drawing greater, or increases the force of the weight; for when the Semidiameter of the *Cylinder* is increased, it makes the proportion of the length of the handle, to the Semidiameter of the *Cylinder* less (by the 10th. of 5th. *Euclid.*) or, that I may speak more plainly, the Semidiameter of the *Cylinder*, is not so often found in the length of the handle; if it happen that the *Cylinder* be not long enough to hold all the Spires, but it shall be needful to put one Spire upon another, since those Spires so put upon one another, necessarily increases the Semidiameter of the *Cylinder*, the same weight will have unequal force, and will sooner move the Clock or Watch, whence it follows that the first hours are unequal and shorter; But if any one would have (for example) the third hour shorter than the rest, let him increase the *Cylinder* of the *Tympane* under the Spire which answers that hour and he will have his desire.

Corollary.

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Corollary. V.

Fig. 49. From this proposition you may understand wherefore in watches, which are not animated by weights, but by springs, wherefore I say the *Cylinder* about which the string or chain winds is not made *Cylindrical* but *Conical*, as in this figure, for when the springs in the beginning, are more stretched than towards the end, therefore they have greater force than the rest; In the beginning they ought to draw by the Apex of the Cone, that is, then there is but a small distance from the Axis, but in the end they draw by the base of the Cone, in which part there is a greater distance from the same Axis; to wit, that greater force drawing from a lesser distance, or in a smaller motion, may be equal to the force of a lesser drawing from a greater distance: For let the force of the spring in the beginning of drawing, to wit, when 'tis most stretched be equal to one pound weight, and in the end equal to the weight of 4 ounces, or $\frac{1}{4}$ part of a pound; the Semidiameter of the Circle of the Cone in which the String or Chain is knit, in the beginning of drawing ought to be $\frac{1}{4}$ part of the Semidiameter of the Cones base, according to which the drawing is made in the end, for thus the force in each case will be equal and will draw uniformly.

Corollary. VI.

Fig. 50. Hence may easily be solved a question oftentimes proposed to me, to wit, whether the same weight hanging on a long cord hath more force than if it hung on a short cord; or whether it be harder to draw the weight A than the weight B, which I suppose to be equal; The reason of the difficulty seems to be because the weight A is farther distant from the Axis of the *Cylinder* than the weight B, and therefore seems to require more force; therefore we say not any distance from the Axis is the measure of the increase of force, but that only from whence follows greater motion; therefore whether the weight exist in A or in B, while the *Cylinder* is turned round once, the weight ascends according to a line which is equal

to the Circumference of the *Cylinder*; therefore in each case the weight is equally moved, therefore equally gravitates; notwithstanding I exclude the weight of the rope, or cord.

But if these weights hang not freely, but the lines *BD*, *AC* should be of rigid matter and inflexible: Because while the *Cylinder* is turned about, the weight *A* describes a greater Circle than the weight *B*, the same weight *A* will have greater force than the weight *B*, according to the proportion of distances.

PROPOS. II.

A Theorem.

WHile a power acteth by the force of its own gravity, the increase of the Power doth not always ought to be required from the distance of the Axis.

Fig. 51. Although we have toucht upon this proposition already: Nevertheless we will fit it peculiarly to this Engin, because that 'tis already known, and in common use with stone diggers; the Machine or Engin consists of a large wheel into which men enter, and in which they walk, also a *Cylinder* about which the rope is turned about, and an oblong neck, in whose extreame or end is a Pulley to direct the weight; It may be questioned, whether the force of the power of the movent applied in the extreame of the Wheel be increased, according to the proportion of the Semidiameter of the wheel to the Semidiameter of the *Cylinder*; to which I answer, it is not so, for when a man walks in a Wheel, and moves by gravity, to wit, by a line tending to the Centre of the Earth, applied in divers parts of the wheel, yea, often times almost under the Axis, Its true distance is not to be taken according to the Semidiameter, as if the man were walking in the point *A*, when he moves by the line *AB*, his true distance is *CD*; as is shewn in Proposition 19.

PROPS.

P R O P O S. III.

A Thorem.

Of the windlace placed vertically..

Fig. 52. **A** Lthough it matters not much how a *Windlace* is placed as to its site or position, yet a *Windlace* whose Axis is vertical hath this peculiar property, that it may be wrought by animals only, because that (properly speaking) animals only have their motion Horizontal, although also some mills are made in which water moves the *Windlace* vertically, yea, and the wind also, as we shall shew; I have often wondered that these kind of *Windlaces* are no oftner made use of in buildings, since by the help of a horse only, greater store of Stones, or Bricks, or Morter, may be conveyed to the upper parts of the building, than by 4 or 5 men; Wherefore a vertical *Windlace* may be worked with a Mill-horse, and about the *Cylinder* a double rope may be turned about, in a contrary manner, so that in the mean while that one weight rises, it sends down the other Instrument. The force of this *Machine* will be very great, for when a horse can carry more than 300 weight, he will draw much more, or raise by drawing; we will suppose 500 weight, and his force increases according to the Proportion of A C to A B; and for the most part A C contains 10 lines of A B, from whence it will be, that one horse alone may raise 5000 pound weight; but if the weights ought not to be so great, and it seem better to raise more small weights with respited force, than to take up a great weight together, and at once, lest the ropes be broke, then you may increase the *Cylinder* A B to any thickness that you please, for then you will lessen the force of the power, and sooner take up the weight.

Nevertheless because in this *Machine* or *Engin* there seems this incommodity, that the weight being elevated, the *Windlace* ought to be turned the contrary way, and there would be

be some loss of time, to turn the horse the contrary way; first 'tis certain that if men were placed to this *Windlace*, that inconveniency would cease: But if yet you would use a horse, make a compounded *Machine* or *Engin* of two *Windlaces*, having two *Cylinders* with teeth, or toothed *Tympanes*, which vertical *Windlace* may move the other Horizontal, so that if the cogs or teeth of the *Cylinder* be put to the other, the *Cylinder* will be moved on one part; but if it incur in the other *Cylinder*, the *Cylinder* will be moved with a contrary motion; and 'tis easy sometimes to move one, and sometimes the other *Cylinder*, with a moveable Leaver about the cardinal point.

Fig. 53. This vertical *Windlace* is commonly used by seamen, chiefly in great ships, so that thereby they take great weights into ships, and draw out great anchors which require great force, both by reason of their weight, as also to dig them out and draw them from the earth, wherein they stick fast; where in one thing is to be noted, that because the Cables or great Ropes are oftentimes so thick, that if they are rolled about the *Cylinder*, and Spire is put upon Spire, they grow to a great mole, and render the *Engin* useles, therefore they turn only 3 Spires or 4 at most about the *Cylinder*, so that while a Seaman turns one end of the rope round it, the other is rolled away; And that it may always consist in the middle, nor run through the whole *Cylinder*, the *Cylinder* is made broader at the ends after the manner of a Cone, as you may see in the Figure, for so the rope is kept in the middle.

Fig. 54. There are reduced to the vertical *Windlace* or Axis in *Peritrochio* your lesser water-mills, in which the water disposed in the wheel forces it so, that the Wheel is moved Horizontally, and its Axes vertically; We use this *Engin* when great store of water is not at hand, and the greater the wheel is, the greater will the strength of the water be, according to the proportion of the diameter of the Wheel to the diameter of the Mill; But in the same proportion decreases the velocity of motion in the Mill, for each turning round of the Wheel, answers each turning of the Mill, from whence it happens that great care must be taken that the Wheel be not made greater than is requisite, for if it be there follows a slowness in the motion of the Mill, and the *Engin* is rendred less usefull; likewise

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Fig. 55.

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if the Wheel be made less than the resistance of the Mill requires, there will be no motion.

To the same Engine are recalled other wheels, which howsoever exposed to the wind, always turn round; for to what wind soever on one part, the Concavity of the little hand turns, the convexity of the other is also turned, as if the wind blew directly according to the line AB , the wind will touch the Concavity of the little hand AGB , and the Convexity of the little hand BA , but then it makes greater impression while it incurs in the Concavity, than while in the Convexity; because then it easily slips away, this Wheel is turned from A by G in B : And the impression of the wind may also easily be hindered in the little hands A , and then it will be turned more vehemently, to wit, if there be placed some obstacle.

This kind of Windlace is used, as often as we use Animals, but chiefly we use Mill-Horses when we work Engines, such as Mills, we grind all manner of Corn with, or Nuts, or Olives, or for the Extraction of Oyl; I omit several other Engines, which part of them are recall'd to this kind of windlace.

PROPOS. IV.

A Theorem.

Of the double Axis in Peritrochio, or a Wheel.

Fig. 55. **T**HE most part of vulgar Engines are not so simple, but that oft times they contain a double Engin of the same kind; I shall not insist upon the Composition, which may be made from a double or triple ballance, or lever; because for the most part such composure is useless, whence the first Composition which may be made for use is the double windlace, and sometimes a triple one, according as the thing requires: But because as we have said, the Windlace is recalled to a lever, and that continually, therefore it will not be unprofitable briefly to note, how wonderfully a power is augmented by using a double Lever; for let the lever be AB . its Prop C , also let AC be to CB , as 10 to 1;

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Sare

Sure it is the Power applied in the point A, is equivalent to 10 Powers equal to it self, applied in the other leaver DF, so that EF be to DE as 10 to 1; the Power placed in F is equivalent to 10 Powers equal to it self, in respect of weight constituted in D: But if the leaver DF impells the leaver AB, the Power F will be equivalent to 100 powers equal to it self, in order to a weight constituted or placed, in the point B.

And the reason is clear, the point F hath 10 times greater motion than the point D, but when the point D is conjoined with the point A, they make the same motion; but the point A runs through 10 times a greater space than the point B: Therefore (by the first principle of this) in such disposition of the Engin, the power constituted in the point F will be equivalent to 100, equal to it self, in respect of weight placed in the point B.

Fig. 56. Which Doctrine is applicable to Windlances, if they are fitted in the same manner; as if the handle AC be 10 times greater than the Semidiameter of the Cylinder B, and the Rope annexed to the Cylinder B, moves the Windlace E, by the end of the handle DF, which also is 10 times as great as the Semidiameter of the Cylinder E: I say the power A is 100 times encreased with respect to the weight G, which is manifest.

Fig. 57. Notwithstanding, because in this disposition the Cylinder E absolves only half the turning about, therefore this Engin is rendred useles in many effects: Therefore if you would know the disposition in which the leaver DE may always draw, this will be, if the Rope be made (as they call it) perpetually turned round about the Cylinder A, encompassing the Wheel BC of the Cylinder D, and this Engin may be most useful, especially when the two Cylinders A and D are distant from each other a great space; nevertheless it hath this inconveniency, that oft times it happens that the Cylinder A is moved alone although the Rope draw not; and therefore they make the Cylinder A, rough with hollowings, and also they make knots or balls in the Rope which enter into the hollowings, and stay the Cylinder that it cannot move alone, as in the Figure E appears plainly.

Fig. 58. We use the same Engin, but in a contrary manner when the power overcomes the resistance of the weight by a long space, but a most swift motion is demanded; as if the
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Fig. XLI.

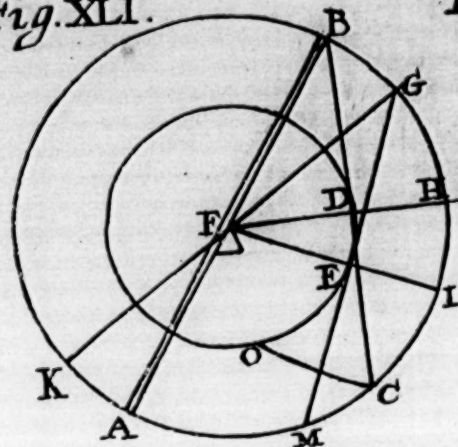


Fig. XLII.

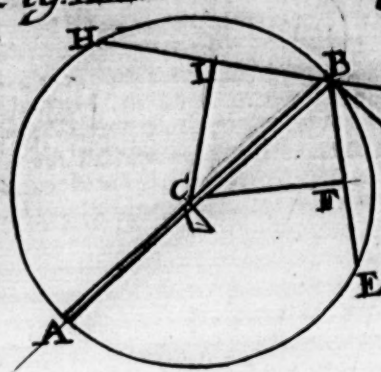


Fig. XLIII.

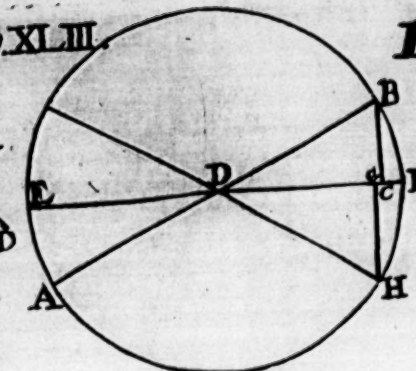


Fig. XLVI.

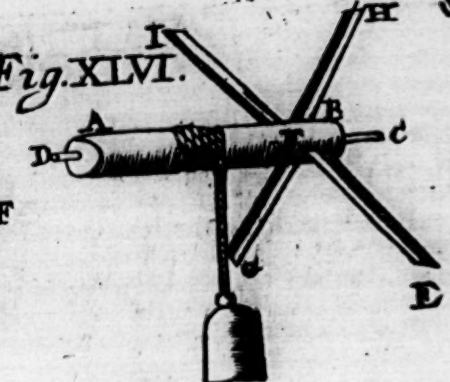


Fig. XLIV.

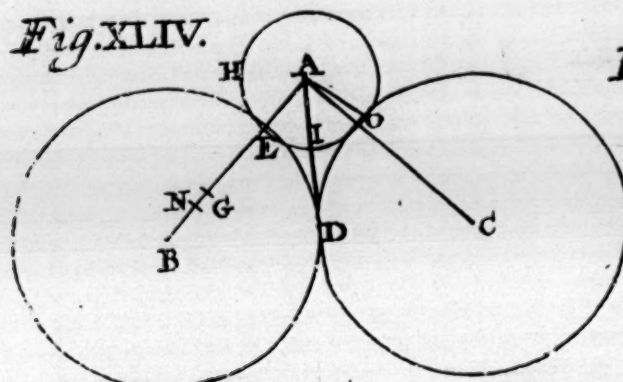


Fig. XLV.

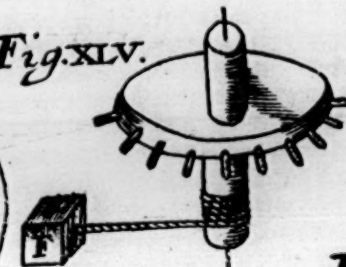


Fig. XLVII.

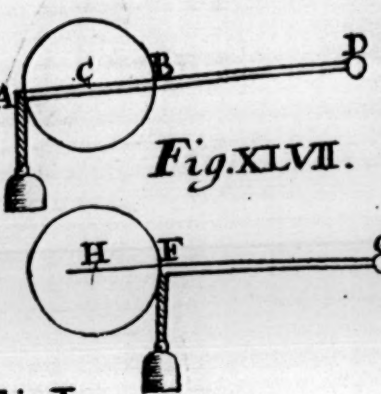


Fig. LI.



Fig. XLVII.

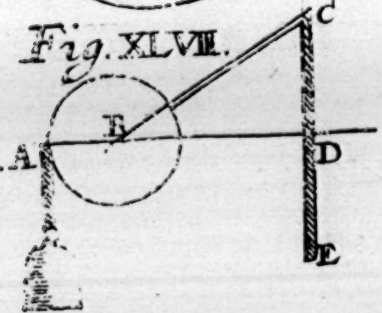


Fig. XLIX.

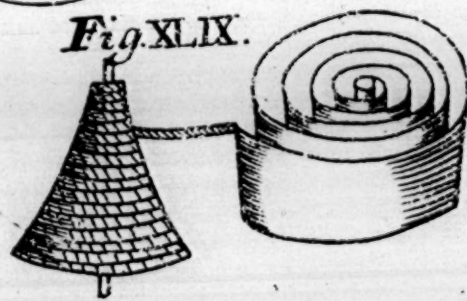


Fig. L.

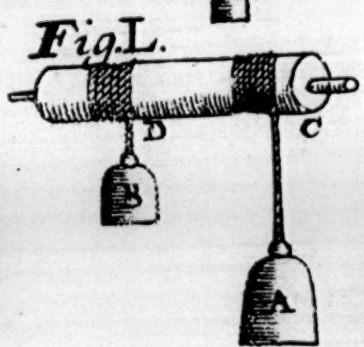


Fig. LII.

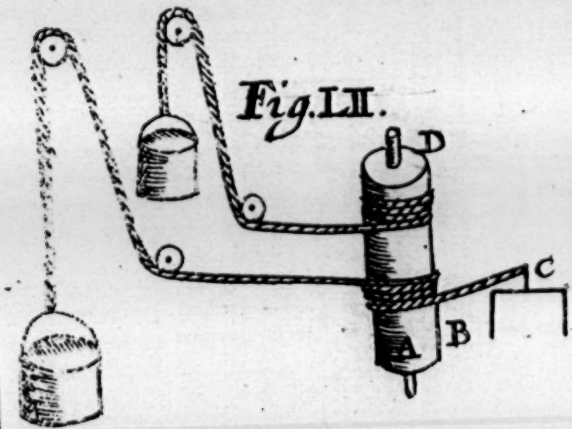


Fig. LIII.

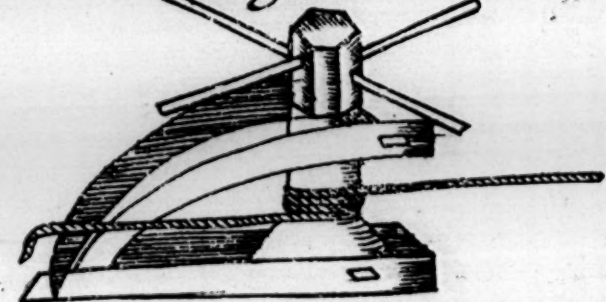


Fig. LIV.

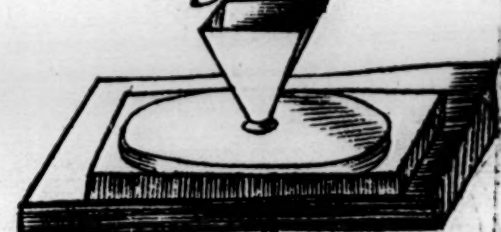


Fig. IV.

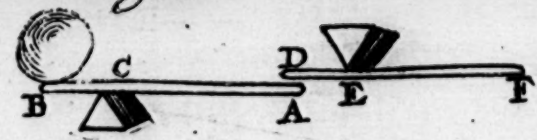
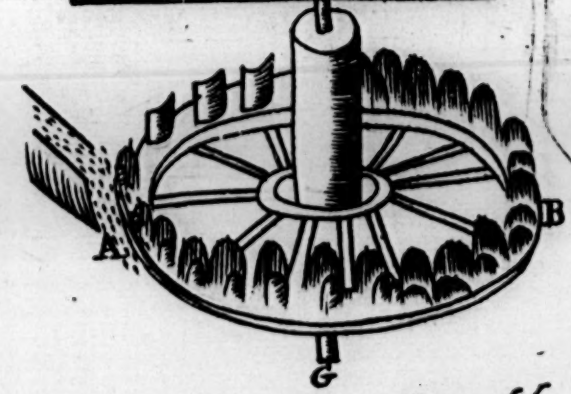
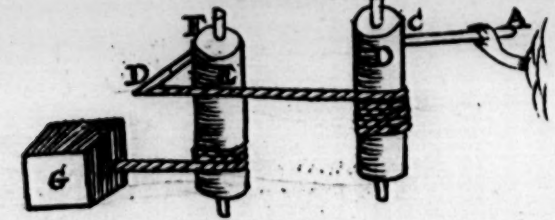
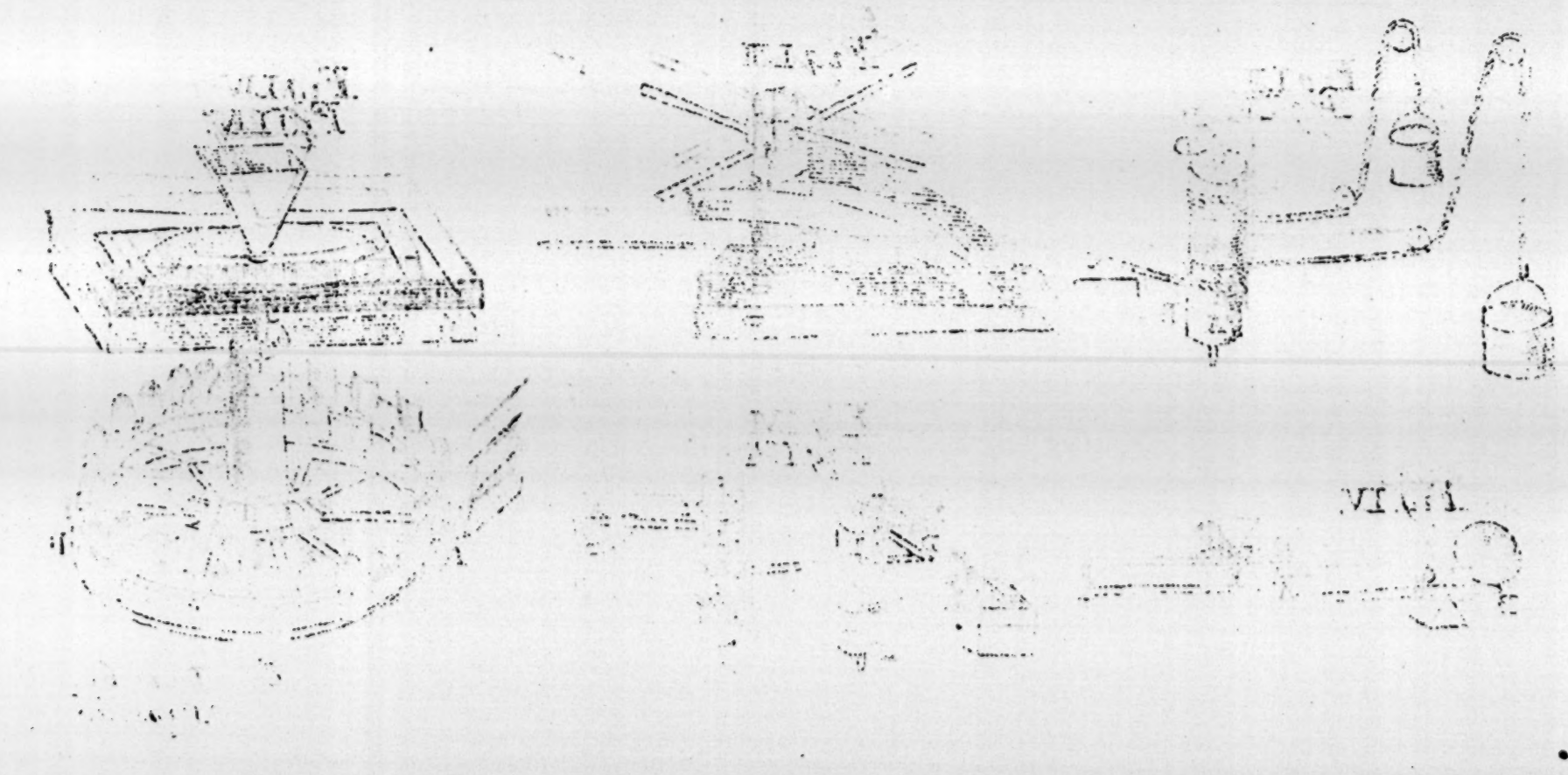
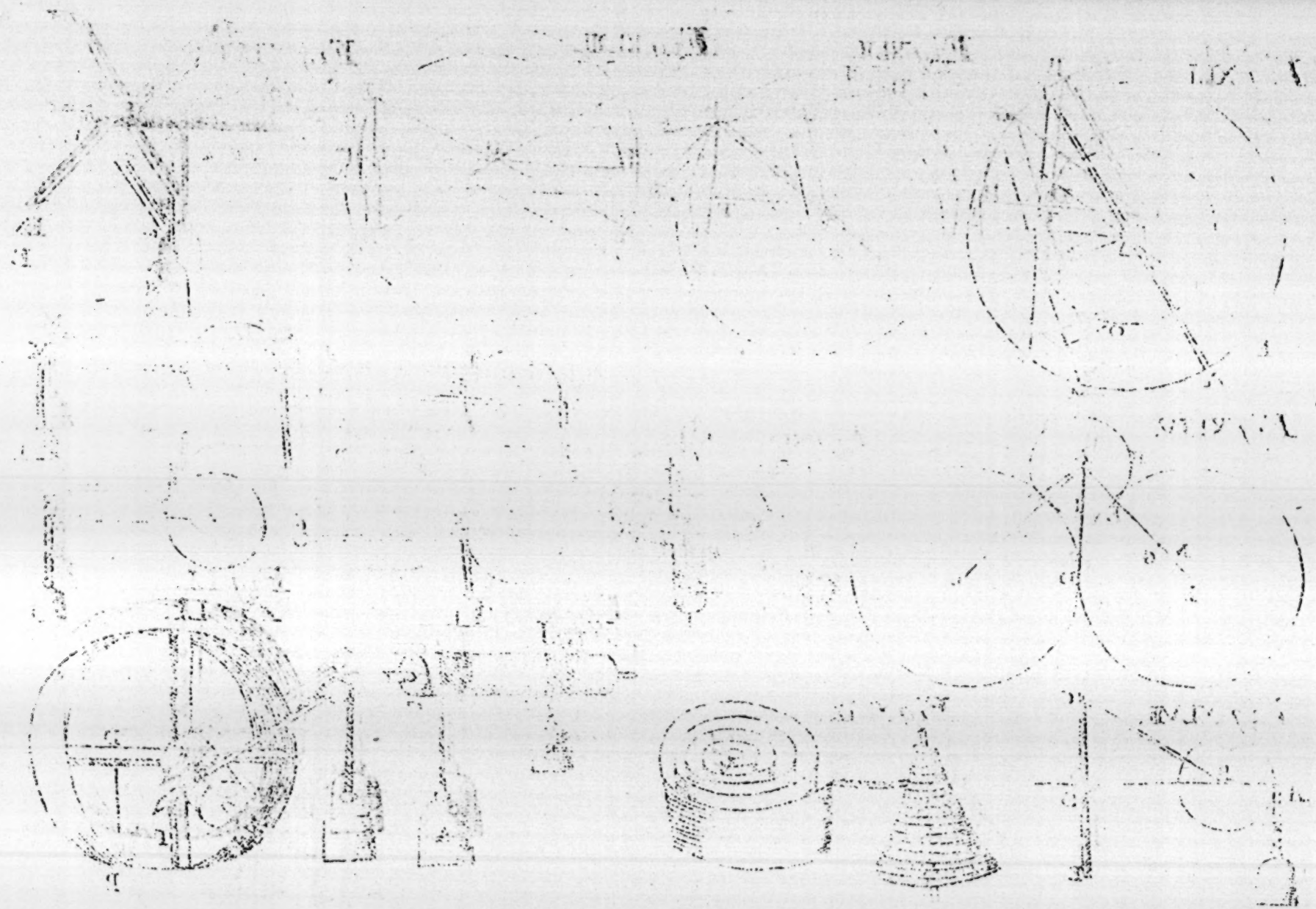


Fig. LVI.





Book III.
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greater Wheel be A about which the Rope is folded, and also about the lesser Wheel B, whose Diameter is contained 10 times in the greater Diameter: 'Tis certain that every circumvolution of the greater will answer 10 Circulations of the lesser; but in this disposition the power is lessened; that is, if the power as 1 be applied at the handle C, you may determine to raise some weight hung to the Cylinder D, there will be required a power 10 times greater to take it up, if it be hung on the Cylinder E. Howbeit this Engin is very useful, because oft times a power overcoming a resistance sustained by a great excess, cannot otherwise conveniently be applied: So they which sharpen Knives, and other edge Tools, on a Grindstone, have greater force than to overcome that resistance, whereby the Iron resists the motion of the Stone while it is held upon it, and requires a swift motion only, which cannot be produced from the power in like manner, because 'tis impossible to move the Arm so swift: In this case an Engin must be used, which encreases the motion, although it lessen the force of the power: This Engin is easie, and much used, and chiefly of Women which Spin; also when they draw out Silken Threads, or double them; also of those that polliish pretious Stones, of Turners, and of many others, and I wonder that 'tis not used by more.

PROPOS. V.

A Theorem.

Of Wheels with Cogs, or Teeth.

Fig. 59. **T**oothed Wheels are recalled to Axis in *Peritrochio*, and are easily understood by a perpetual leaver; wonderful is the increase of power in using such an Engin.

For since that while one Wheel is 10 times turned about, the other is but only once turned round, it causes each Wheel to increase in a decuple proportion, and therefore as shall

be demonstrated elsewhere, a number consisting of 50 Arithmetical Figures, is greater than the number of Sands which the whole Circuit of the Firmament can contain; but the number of each Figure added, increases in a decuple proportion, and from thence the power follows.

The Demonstration. Let there be a power in A which can draw to it self 100 pounds, and let C D be 10 times the Semidiameter E F, and let there be so many Teeth in the Wheel G, that E F may describe 10 orbs in the same time that the Wheel G describes one; Moreover let G be 10 times turned round while the Wheel L absolves one circumvolution, and so on; I say, the Power, as 100 placed in A, is able to elevate a weight of 100000 pounds.

For since the power in A runs through a space 10 times greater than the little Wheel E F, and the little Wheel E F 10 times of the little Wheel M, and the little Wheel M 10 times more than N, and this again 10 times more than the Cylinder G H: The power A runs through 100000 times greater space than the weight P; but the power is increased according to the proportion whereby its motion exceeds the motion of the weight (by the first principle of this) therefore the power A in respect of the weight P, is equivalent to 100000 powers equal to it self: but A is supposed to be able to draw to it self 100 pound, therefore 'tis equivalent to 10000 powers which can each draw 100; but 10000 of such powers can draw 1000000; Therefore the power in A, by the help of this Engin can draw 1000000 pounds, which was to be demonstrated.

But on the contrary the weight loses as much of its force; whence if instead of the weight P, a power be placed which can elevate 100000 pounds, and the weight in the point A can only elevate a weight of one pound, but the loss which the power A suffers, is in time, for it ought, to make 1000 Circumvolutions in the same space of time that the Cylinder I, absolves 1.

Also this Engin is inverted, or changed, as often as the force abounds in the power, and a most swift motion is required in the weight, which may easily be understood by the foresaid discourse, to wit, if the handle be in the Axis I, 'tis certain, that the Axis D E makes 1000 Circumvolutions in the same time that I only makes one.

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Fig. 60.

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PROPOS. VI.

A Theorem.

To recall Toothed Wheels to the Leaver.

Fig. 60. **T**HE whole multiplication of a power by help of Wheels, is easy to recall to Leavers, yea he, that dilligently considers the nature of Wheels, may easily consider the perpetual leaver in them, for each Cog of the Wheel is a Leaver, which are substituted to themselves by turns, so that one being deficient another succeeds it.

And that we may consider the same in the Multiplication of leavers, let there be 3 leavers A B, D E, I H, and let A C be to C B as 1 to 10; in like manner D F to F E, and E I to I H: I say the power as 1 in H in respect of the weight A, is equivalent to 1000 powers equal to it self.

The Demonstration. H is 10 times more moved than E or F, and E 10 times more than D or B, and B 10 times more than A; Therefore the motion of the power in H is 1000 times more than the motion of the weight in A: but if there should be only one leaver K M it would be otherwise, for the leaver L M would be only 30 times the part K L, and so the power in M would be equivalent only to 30 powers equal to it self.

To this kind are recalled almost all Engines of any moment which we commonly use, and which in the following propositions I shall explicate, the Forces whereof if any one would consider, in general he must measure both the motion of the weight, and of the power, and compare them between themselves.



PROPOS.

P R O P O S. VII.

A Theorem.

Of Engines moved by Water.

Fig. 61. **A**Mong others those Engines are most useful, which are rather moved by Inanimate things than by Animals; because that Inanimate things want not nourishment, and are never tired or wearied; but Inanimate things which are wont to Animate Engines, are likewise all those things which cause Motion, as Water, Wind, Smoak, any kind of Weights, Springs, &c. In this Proposition I shall briefly handle those Engins of that kind which are moved by Water: And I find that Water can move an Engin in a double manner, either by an acquired force which can equalize a percussion, or simply by weight or gravity, thus some Wheels are made which bear Water on one part; in which 'tis requisite to know the precise proportion of the Axis in *Peritrochio*: So that the weight of the Water may have the exact proportion of the Power, and we ought to measure its force by the distance from the Axis, which in such case the forces of the handles bears: but when running Water moves an Engine or Machine not by force of weight, but by acquired force, that is done either because Water is conveyed by a plane much inclined, or running into wings, or little hands, but which method is best we will examine when we come to treat of *Hydraulic Engines*.

Fig. 62. But 'tis certain that greater Wheels have most force, for when in Windlases the power is moved by a longer handle its force is increased, but likewise a requisite time is increast; whence I often find in common Mills unnecessary Expences laid out, to wit, they make the greater Wheels winged, in which the Water dashes, also because a slower motion should follow in the Mill, they add a greater toothed Wheel which runs into a lesser; so that while the greater makes one revolution, the Mill makes

makes 8 Circumvolutions; It is sufficient that the first wheel A B, equipt with little hands, be made less by one half, also the wheel C D to be $\frac{1}{2}$ of that; so that E F shall make only 4 Circumvolutions in each rotation of the greater wheel A B; for the Water hath the same force in respect of the Mill E F, in moving by only 4 turnings about, and the Water will twice as soon turn the wheel A B, being lesser by half; and if we weigh or consider all these things exactly, and according to Mathematical Rules, the same thing would happen if the wheel A B should be eight times lesser, likewise C D should be 8 times lesser; so that each Circumvolution of the Toothed, or Cog wheel, should answer each Circumvolution of the Mill E F.

Which things, as I have said, are true, precisely speaking, notwithstanding we must consider one thing, *viz.* That greater wheels because they depart less from a right line, therefore their little hands are longer forced by the Water; but in lesser wheels each little hand is sooner elevated, whence in all these some mediocrity ought to be observed.

Fig. 63. Not only Mills for grinding of Corn, but also most other Engines, yea, almost all which are made in Water are reduced to this kind; First, all Mills for Corn, which are made on the banks of Rivers, or those that are made in little Ships, and in the middle of Rivers, or other Engines which are for grinding of Nuts, or of Bones to powder, &c. Also Engines to make Paper, in which a wooden Cylinder of sufficient magnitude standing out, furnished with little troughs, takes up wooden Mallots, which bruise and break whatsoever is laid under them to powder; your Gun-powder Mills in like manner consisting in a Cylinder, equipt with like troughs, which take up Pestles of Mortars; for in all these we must consider Axis in *Peritrochio*, as well in the wheel which the Water forceth or driveth, as in the Cylinder and its troughs, taking up Mallots, or Pestles.

Fig. 64. Likewise Mills for Iron, in which also a Cylinder equipt with little hands, takes up and lets down an Iron Mallot of a sufficient greatness.

Fig. 65. And these are of divers kinds, according as they are diversly required to be made, for some are greater, and some are lesser, some pound finer than others.

Fig. 66. Saws also which are drawn up and thrust down by the handle; also there is another part of the Saw which belongs to another kind, *viz.* to the Screw. Also Engines in which Bellows are wrought, or blowed, which belong to the same manner, as to motion upwards and downwards, but if four pair of Bellows are to be blowed together, the Axis ought to be made turning, or bowing, four opposite ways, that they may be moved in any order, and in each Quadrant.

PROPOS. VIII.

A Theorem.

Of Engines that work by the gravity of Weights.

Also Engines are moved by Weights, and the force of their Gravity, as are our Clocks, notwithstanding I shall say in general, that all those Engines are not fit to augment the force of Powers, but to shorten time, to wit, that that may be done in a short time, which was wont to be done in a whole day; that is, let an index of hours be moved in a whole day, that it may shew the hours properly, if a man should undertake that without an Engine, he would spend the whole day; a weight being substituted by a man in one minute, in drawing or winding up the weight, uses as much force as is necessary to move the Hand or Needle the whole day.

The same I say, of Engines for the turning of Spits in convenient places, which have nothing peculiar but their motion of staying, or stopping, which we shall treat of hereafter; and these Engines are made after four manners, *viz.* with Weights, with Springs, by Smoak, and by some living Creature walking in a Wheel; of Weights and Springs I shall say nothing, for 'tis most certain I have found nothing in them more than toothed Wheels, and Axes in *Peritrochio*; and the Animals which are commonly made use of for the turning of Spits, are Dogs, but Geese are better, for they will bear their Labour longer, so that if there be need they will continue their Labour 12 Hours.

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PROPOS. IX.

A Theorem.

Engines moved by Smoak.

Fig. 67. **E**NGines which are turn'd by Smoak, shew plainly how much force is increased by Axis in *Peritrochio*, for what force can there be less to impel and move a Weight than Smoak, nevertheless while this runs into the winged Wheel A B, all whose wings are bent in the same part, if the wheels are so fitted, that while C D makes four or five Circumvolutions, the wheel E makes one; and in like manner while the wheel E, or that annex to it F, is turned four or five times, the right line G is only once turned; A B makes 25 circulations in the same time that G, viz. the Spit makes one, I say, from this multiplication of motion in the power, to wit, in the Smoak, or in the wheel, into which the Smoak enters, the impulsive force of the Smoak is increased 25 times, with respect to the resistance of the Spit placed in the point G, and I do not see any thing more in this Engine worth our taking notice of.

PROPOS. X.

A Theorem.

Of Engines working by the Wind.

Fig. 68. **T**HE reason is the same of Mills turned by the Wind, in which also the sails are bent in the same part, for they are not directly opposite to the wind, but every one in one and the same part are somewhat oblique,

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almost in the same manner that Boys make paper Wheels on a Reed; so that while they run and hold it in the Air, 'tis easily turn'd, and because the force of the Wind and the violence is very strong, the Mill makes more turnings about than the winged wheel in a contrary manner, as in the precedent Engine. And the same question may be made of this kind of Wind-mill, which is made of common ones, to wit, whether they may not be more compendiously composed than commonly they are made; for since by the multiplication of the Wheels the motion of the Mill is increast, whether or no it would be better to make lesser wings, whence it will come to pass that the first Wheel will compleat its revolution sooner, and therefore there will not need so much multiplication of the Wheels, that the first Mill should obtain the same motion; 'tis also worth our consideration that the wind is not applied in one place only, but almost in the whole wing or sail, and therefore the greater the sail or wing is, the wind will not only have the greater force, because that it makes greater motion in the extream with respect to the motion of the mill, but also more plenty of wind is adhibited, whence I think 'tis better to use longer wings or sails than shorter.

The Art of Mills depends on Axis in Peritrochio.

TO reckon up all the Arts which depend on Axis in *Peritrochio* would be a thing not unpleasant, but almost an endless piece of work, and would be rather like a History than a Theorey, in which I chiefly write of the principal causes of Engines, shewing by what ingenuity every one may design or contrive Engines after his own manner meet for the purpose. And I shall insist a little on the making of Mills, that we may know how great profit we receive to the commodity of life from Axis in *Peritrochio*; and although those that are chiefly ordained, are Mills for grinding of Wheat, and other Seeds, that bread may be made of flower, yet some part of them are designed to other uses; for as much as the outer Wheel is common to all, which by water running into it, turns it and the Axis about. For if Wool, or Hemp, or Flax, be to be pounded, or any body ground to Powder, if old Rags are to be

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be beat to pieces to make Paper, little pegs or pins are fixt to the Axis, which in turning about meet with the pins of Pestles and raise them, and depress them, and their weight falling on the matter laid underneath, either batters or breaks it to pieces, or beats it to powder in Mortars.

In the same manner Pestles may be disposed to match with their hollow Cylinders, which being elevated by the little pins of the Axis, attract the water into the hollow Cylinders, or rushing in naturally they admit it through the Cells, then falling down by their gravity, they press the Water through the Tub, and force it to ascend to an higher place. Or if you like not Pestles so great and heavy, and would force Water to a higher place, dispose a pair of Pestles by a Rope, or Chain, put through the hollow of the upper Wheel, and passing over the Periphery joins them, or rather overthwart, like weights joined to a Beam, so that while one is depressed the other is raised. And the pin of the Axis depresses the Pestle, by whose force the water ascending in the Tub is prest, and the other Pestle being lifted up draws the Water placed beneath, which in like manner is prest down after that by the pin of the Axis answering its pinion; from hence it comes to pass that a longer Axis may be added to the Wheel, and more pairs of this kind of Pestles in like manner may be disposed, and the pins in the Periphery of the Axis so distributed, that not only more Pestles may press or force down together, but every one after another, if the power turning the wheel be not altogether so strong, if not, and it should be stronger, you may depress more together, and raise those that answer them; unless by chance it please more, to make use of two pair of Pestles in the same manner, with so many pins placed in the Axis, that in one going round of the same Axis, the same Pestle may be depressed twice or thrice.

Moreover to this place appertains, what we see in many places in the Work-houses of Hammer-Smiths of Copper or Iron, where also the outer wheel being turn'd about, and the force of water failing, the inner wheel in the room turns as if it were turn'd by the hand, which radius of the upper Axis is fixt parallel to the Horizon, and a rule joined to it that may be folded in the Joints, while it lifts up and depresses that which is overthwart; on the other end of the same Axis, taking up in like manner from hence, and depressing from hence,

it procures an altern or changable motion to the Bellows ; and the other wheel receiving a stronger force of Water falling down, and turning its Axis about, the pins fixt at the other end of the Axis depresses the little rafter or leaver, whose opposite end being raised, is joyned to a great Iron Hammer, which besides the fall of the Axis with pins of it self, lighting or falling upon the subjected copper or Iron being burnt in the fire, beats or hammers it.

In all these the Semidiameter of the Wheel is to be consider'd, in whose little branches standing out the water running into, retains the force of the moving power ; but the Semidiameter of the Axis is not to be consider'd alone, but also the length of the pins that stick out to be added, so that from both is made one only Semidiameter of motion which is communicated to the pestle, or to the deprest end of the Hammer or Sledge. I say, to the depressed end of the Hammer, for the elevation of the Hammer is somewhat greater than its depression that a stronger blow may follow ; for neither the little rafter or leaver is altogether equally divided from its Axis on which it stays upon, but the Hammer is a little farther from it, than the opposite end which is depressed, and therefore the depressing force is greater than if the leaver were distinguished into equal parts. Likewise in the motion of Bellows ; first, the Semidiameter of the wheel is to be compared with the adjoining handle, moreover the radius fixt to the superior Axis, must be compared with half the piece that goes a cross to which the Bellows are joined, and from these two proportions is compounded a proportion of motion, or movement of the power, to the motion or movement of the weight moved.

But yet in Mills whose grinding stone for Corn is turned round parallel to an Horizontal plane, yea, and that very swiftly, that the grain may be dissolved into flower, 'tis not enough that the outer wheel receives force from the Water turning the Axis fixt to it, but also the lower toothed Wheel is required to be in the same Axis ; and that the members, or parts, of the Engine be not multiplied in vain, they commonly so dispose the Mill-stones, that the Iron Axis that sustains the upper Mill-stone, being furnisht with a place to turn, or run in, obtains the lower place, and therefore the runner as near as may be touches lightly, the upper part of the neither toothed Wheel with its plane, having the same Axis with the outer Wheel.

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But if the Mill-stones cannot be placed in a plane beneath, or above that which turns the lower toothed Wheel, but only a little beneath, or above, the Axis of the same Wheel; because the chamfred turning joint joining very near to the Mill-stone, and so turning the Stone, is distant from the toothed Wheel, and this doth not so conveniently admit of such long Teeth which the same turning joints, or the little rods of the runner, are able to mix with fitly; therefore there is required another Axis perpendicular to the Horizon with a runner, and a fixt Wheel, which shall turn about the lower Wheel of this Runner, forcing its little Rods with its Teeth; for the toothed Wheel parallel to the Horizon, being fixt to the same perpendicular Axis, is turn'd about together, and being joined with the runner of the Mill-stone turns it round.

Here also are many proportions compounded, the first is the proportion of the Diameter of the outer Wheel, to the Diameter of the inner Wheel in the same Axis; moreover the proportion of the Diameter of the Runner of the Mill-stone adhering to the Mill-stone turning round the Diameter (whether the whole Diameter be allowed, or only that part which is the Diameter of the Circle in the rotation of the Mill-stone described from the point between the Centre and the middle of the Periphery) and if, as in the second case, the perpendicular Axis must be placed between; besides in the Composition, comes the proportion of the Diameter of the runner to the Diameter of the toothed Wheel, perpendicular in the same Axis; from whence it appears to be better, that the Diameter of the inner Wheel be less than the Diameter of the outer Wheel, that the force of the Water forcing this may be more strong; but also we must take heed that we do not make it too little, so that its number of teeth scarce exceed the number of little Rods of the runner adhering to the Mill, for this will cause it to move too slowly; and if the perpendicular Axis be in the middle, supposing this equality of Teeth, and of the little Rods of the runner, one turning round of the outer Wheel will only once turn round the toothed Wheel parallel to the Horizon, and therefore in the same time the Mill will be only so many times turn'd about, as the number of little rods of its runner is contained in the number of Teeth of the toothed Wheel fixt in the perpendicular Axis.

But

But as you increase the number of times of the Mill's turning round, take heed that the difficulty of moving in like manner be not increast more than needs must; to wit, if the Diameter of the runner in the perpendicular Axis be excessively less than the Diameter of the Toothed wheel in the same Axis; if so be, a power applied in the runner will be moved much slower than a weight applied at the end of the wheel with Teeth, and therefore the difficulty of moving increased: Wherefore all things must be wisely administred, that neither the force of the moving power be tired in vain, nor the Mill be moved slower or swifter than need is.

But if it please not, or the disposition of the place permit not the middle Axis to stand perpendicular, but it happens more conveniently to be parallel to the *Horizon*, then the Teeth of the inner wheel having the same Axis with the outer wheel must not be fixt in the plane, but require to be fastned in the extream Periphery, that they may turn the runner of the superior Axis, (whether greater or lesser, according as is needful) and with it the wheel that is Toothed, not in the Periphery, but in the Plane, from which the runner of the Mill is turned.

Neither otherwise than before, is the proportion of force compounded, to wit, of the proportions of Tympanes or Water-mill wheels, or Crane wheels, which have a common Axis, as appears from what hath been said.

Hence we observe, because the moving power is Water, that the form of a wheel receiving Water is not to be always the same; for those wheels which are placed in a running Water would be inconvenient if they have a very large Diameter; or if but a little Water falling, the Impetus or force will be repelled, if the little hands be prepared to small. Therefore wheels of this kind should have indifferent Diameters, but the little hands possess a very considerable part of the Axis, being displaid very nigh the length of the Axis, that so by much Water running into them they turn round with a stronger force; so in the River *Poe* in *Italy*, commonly the length of this wheel is 15 Feet, the whole Diameter 9 Feet; the Diameter of the neither Stone is 8 Feet 3 Inches, having 108 Teeth fixed in the plane, and the runner of the Mill is distinguished into 9 Spindles; and the Stone of the Mill in thickness 6 or 7 Inches, and its Diameter 3 Feet 9 Inches: But
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because the motion of Water falling from on high is greater than of a running Water, therefore the Diameters of the wheels ought to be larger if there be need, and it suffices if the breadth of the little hands be very indifferent, as being included in a Channel or Pipe; by which the Water falling decays, or is lost: That is to say, a little Water falling from a Plane more elevated, hath greater force than from a Plane almost *Horizontal*; and besides a wheel of a larger Diameter is easier turned although from less water, for it hath greater proportion to the inner wheel from the other pairs. Moreover the little hands commonly are plain, or but little bent, so that the water may run abroad here and there; nevertheless sometimes they are concluded on each part with a ledge, or welt, as it were a little Vessel containing water for sometime, so that the weight of the included water helps the turning, by pressing downwards; Moreover in an inclined channel, the force of the water is greater in the lower part than in the upper near the beginning of the fall; to wit, because water naturally descending hath an accelerated motion, and acquires an impetus from the descent of the antecedent.

Hitherto we have considered of Mills which are drove by the force of water, adding nothing concerning those which are turned by Men, or by living Creatures, for these have nothing peculiar, besides that the Axis of the first wheel which procures the motion of the rest of the consequent parts, is perpendicular to the *Horizon*, because a power moves easier in a *Horizontal* plane, than in a vertical wheel, or Tympane, which is trod or trampled on; and instead of the outer wheel driven by the water, a Bar is fixt to the Axis, which they either draw by Cattle, or work with Men.

Notwithstanding we will say somewhat of Mills which are wrought by the Wind, whether they be for grinding of Corn, or bruising of Fruit, or whether they be for working of Pumps, whereby waters are drawn from low grounds that are overflowed: For that which belongs to the inner artifice of wheels and runners, are like those which are found in our Mills moved by the force of water, unless that in those, that being remote from a level plane (if so be a fit place be granted, and the wind caught by a large van) they ascend by a pair of Stairs, and the Corn, or Fruit, is carried into the upper place which they intend to grind, bruise or break, and the

Flower

Flower is transferred from thence: which labour the Miller may be eased of, if by the same labour whereby the wind turns the prime Axis with its wheels; Sacks full of Wheat, or Flower, may be taken up, or let down, with a Rope drawn about the Axis, being lapt up, or unfolded: That which is chiefly to be considered in this kind of Mills, is that which pertains to the Vans, or Sails, which receive the wind, for even as the plane of the wheel is not directed according to the running of the water, so neither have the Sails such a disposure that they follow the leading of the wind: But the upper part of the little House wherein the Axis with the Toothed wheel is contained, is turned about until the Vans, or Sails, are set against the blowing of the wind.

And the Vans or Sails are as it were 4 Ladders conjoined at right Angles in the end of the prime Axis, each whereof is covered over with Linen Cloath to resist the wind, which if it be pretty strong, the folded part of the Cloath will admit of some passage to the wind; notwithstanding these Vans or Sails, are not so equally placed, as to be in one and the same vertical plane, but the plane of each Sail is placed *oblique* to the other side, withdrawing it self by little and little from the wind; whence it makes the wind running between the intervals of the four Sails to repel on the sides, and as it were to smite the Sails by an Elbow, and so the Axis is turned according to the Inclination of the Sails; for if there were no *obliquity* of the Sails, and all as it were made one plane in which the Axis would be perpendicular, it would be uncertain in which part the turning would be; that which belongs to the breadth or length of these kind of Sails *obliquely* placed, 'tis not doubted but that the breadth of them helps the motion very much, because being placed in the same *obliquity*, a greater part of the Air runs into a larger than a narrower Cloth; and in a very strong Wind, least the velocity of the Engin be over much, we find sometimes that covering half the Sails with Cloth will do; but whether or no 'tis worth while to encrease the length of them, is uncertain: For although a power more distant from the centre of motion hath more force, notwithstanding, because the ends of long Sails are very much distant between themselves, the wind having obtain'd a larger space, hath less force; as also water flows swifter, and with a greater
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endeavour through a small narrow place, than it runsthrough a wide open Channel; therefore I dare not intirely define in these kind of Sails, in what place the forces of the moving power should be placed, as it were in the centre of vertue, or force; for near the Axis to which they are fastned, the distance is small, and the Wind as it were their object being stopped, blows more swiftly: And further from the Axis in a greater space, it slides away more easily, and less incites the course of the Sails; but for as much as we must not rashly appoint the compression of the wind altogether to answer the changeable distances of the Sails, which are in the same proportion as their distance from the Axis; neither can it easily be affirmed, that the force of the Wind by compression doth decrease in the same proportion, whereby the same motion increases by the distance from the Axis, from whence there would be a compound motion of the distance from the Axis, and of the force of compression to be equally diffused through the whole length of the Sail or Vane, and therefore the centre of the moving force would be in the middle of the length. Nevertheless all things rightly considered, I esteem the centre of this force to which the power is understood to be applied, to be not far from the middle of the length of the Vane or Sail, unless by chance the Vanes should be such, that their breadth be increast by departing, or being placed further from the Axis, for so the distance being lessened in the ends of the Sails, the compression of the wind is likewise increast.

But if you imagine any inconvenience to happen, by the Poles lying upon the little House, and its being turned so, as the sails to be again the wind which they receive; you may on the top of the House in an open place exposed to all Winds, place an Axis of sufficient strength perpendicular to the Horizon, about which you must place the toothed Wheel parallel to the Horizon, from whose turning about, the Mill at last is turned; and the breadth of the sails according to the length of the Axis, must be placed in the same upper part without the Roof, that the Wind blowing, they may receive the force of it; even as Water flowing, the force is received by the little hands of the Wheels. But because plain even sails, seem less apt to continue the rotation, since those which are opposite to the Diameter, are at last equally exposed to the force of the Wind, and would be forced neither to the right

hand rather than to the left, and therefore the turning round would cease; therefore the sails should be made a little crooked, or bowing, for by this reason they will be made so, that the opposits will be unequally prest on, and the Wind will attack with unequal force the convex face of the right, but the hollow face of the left Sail, to wit, it doth as it were remove it self to the Wind, neither is the end of its motion very much opposed, according to the bowed direction of the Wind; and I make this hollowing so bending every way, that receiving the Wind, it receives its whole force: Moreover the particles of Wind incurring in the two Sails that are next each other, are reflected from the convex of one face to the hollow of the other face, and increases the force, or impulsion; but if you please not to have four, but five Sails, lest at any time two be opposed by the Diameter, I shall not deny it. Certain it is, that the length and breadth of these kind of Sails help very much, for the larger they are, the more wind they receive, and the longer they are, the further they be from the centre of motion, and have more force: But how the Machine, or Engin, must be stopt or stayed by folding or unfolding the covering of Cloth, that it do not work when the Miller would have it stand still, I shall not here dispute, where we are only considering the force of moving; neither doth the sole use of this Mill consist in grinding of Wheat, or other Grain, but also in raising and turning waters another way, that marshes may be drained, and other things of the same kind, which present body always moving, they are not tyed to a certain time, even as in the work of grinding, which is not always used.

Mecha-

Book IV

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Mechanick-Powers.

OF THE

PULLY, &c.**BOOK IV.**

A Pully is an Engin consisting of one or more little wheels turning easily about their Axis, in which a Rope being drawn about the wheel, we draw, or raise a weight; there is no need of a larger Definition, since almost every one knows, and hath seen this kind of Engin, although there are very few that understand their force rightly, or wherefore they are used; and sometimes 'tis wont to be used with one wheel only, and then 'tis called *Monopastos*, or of a double wheel, and is called *Dispastos*, or 'tis trebly multiplied, and is called *Polypastos*.

PROPOS. I.**A Thorem.**

A Single immovable Pully neither adds nor diminishes Force.

Fig. 69. **L** Et there be a single immoveable Pully A B, so that the wheel only is turn'd about its Axis, and let the snatch block be immovable; I say, that Pully will not

encrease the force of the Power, properly speaking, so that the whole advantage which accrues from such an Engin, is, that the Rope be not worn, and that difficulty skun'd which arises, not exactly from the weight, but from the wearing of the Rope.

The Demonstration. An Engin then helps not the Power, when the motion of the Power and of the weight is equal; but in the case proposed, the motion of the weight, and the motion of the power are equal, which I thus make appear: First, understand the weight in D, and the power in E, draw the Rope, and the power drawing the end of the Rope descends in the point G, and in the mean while the weight D ascends in H, because in both sites or positions the length of the Rope is not changed, D A E will be equal to the Rope H A G, and by subtracting the common segment H A E, there remains the lines D H, E G equal; but E G is the motion of the power, H D the motion of the weight; therefore the motion of the weight and of the power are equal, wherefore the weight is neither increast nor diminisht, and the power hath the same force only, because if by it self (no Engin intervening) it be joined to the weight, it moves so much as the weight; therefore the force is increased nothing by this Engin; which was to be demonstrated.

PROPOS. II.

A Theorem.

A Power is easily applied by a single immovable Pulley.

L Et there betwo Powers; suppose Men, raising equal weights, and let one use a Pulley, and the other no such Instrument, I say, the first can easier apply his force or strength to such weight, than the second; for either the weight will be placed beneath the Man, or above: If the first, the endeavour will be so, that the tractive force of the Man in such case will be posited in this; that the Man will be a little bent, the force of the Nerves will endeavour to restore themselves to their wonted

Book IV
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wonted rectitude, or to hinder such bending or crookedness; therefore when a weight is taken up in this manner, oft-times the endeavour is in the knees and the whole Body; or the weight to be raised is placed in an upper place, and then in like manner we must have recourse to the force of the Nerves, but when we use a Pulley hung in an upper place, we may apply the weight of our body, besides this kind of force of the Nerves, and oft-times without any endeavour of the Nerves, therefore 'tis not so troublesome.

PROPOS. III.

A. Theorem.

Large Pullies are most useful.

Fig. 71. **A**Lthough as I have shewn in the first Proposition; that one Pulley whose Snatch-block is immovable, neither increases nor diminishes the force of the power; nevertheless we have said also, it adds to the facility, because that it saves the wearing, or rubbing of the Rope, but there is found some, although but little resistance, in the Axis of the Pulley, which ought to be turn'd about; I say, this difficulty will be lessened, by how much the Orb of the Pulley is greater, for than the Semidiameter of the Pulley, or Rundle, is as it were a Leaver, and the Semidiameter of the Axis as it were a *Cylinder* in a wheel, or *Peritrochio*; and by how much greater the proportion of the handle is to the *Cylinder*, so much the easier is the motion; as because there is greater proportion of the line *GD*, to the radius of the Axis, than of the line *GB*, the resistance is easier overcome, which is made in the circumference of the Axis, while the Pulley is turned about it.

There is also another conveniency in large Pullies, to wit, that the Rope is not so often folded, and consequently not so much rubbed, or worn; but I suppose alwaies Pullys to be moveable about their Axes, for if they should not, we must reason otherwise.

P R O P O S. IV.

A Theorem.

*A Man may take up a Weight heavier than himself
with a single immovable Pulley.*

THIS Question hath been put to me more than once, whether or no a Man can take up, or raise a weight heavier than himself, with a single immovable Pulley (I always understand the Snatch-block immovable) or whether a man that weighs 150 pounds, can raise a weight of 200 pounds? But I devide the case, to wit, either a man so singly stands, that the force of his weight, or gravity, only insists on the Pavement, or his Knees, and his whole body so indeavours, that the force of this endeavour adhears to some other Body; if this second happen, a man may elevate a weight heavier than himself, to wit, because, besides the weight of the man which may be all applyed, there may be also a contrary endeavour from the resistance of the Nerves, so that while I would take up one, with the Pulley I take up more; some Knees endeavour so, that they cleave to Benches, or Formes, and lift up the Benches together with them, whence from such endeavour an union is made of the Benches with the Man; that I may better explain my self, suppose a man has 50 pound weight upon his Feet, and both his hands to lay hold on a Rope fastned in an upper place, if the weight on the other part be very great, the man may by hanging on the Rope lift up his Feet, and elevate or raise the weight of 50 pounds, in which case, besides a weight equal to himself, he may elevate 50 pounds.

But if he singly stands on the Ground, experience teaches us that he will only elevate 150 pounds.

But we must argue otherwise in drawing of weight insisting on the ground, or on an inclined plane, for since weight doth not precisely resist an *Horizontal* motion, a certain rule can scarce be made; for it depends on the evenness of the body on which the weight stands, or lies.

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 PROPOS. V.

A Theorem.

Many immovable Pullys neither increase nor diminish the force of a Power.

Fig. 72. **L** Et the several Pullys be EFG, whose Snatch-blocks are immovable; I say, although we use them altogether, the force of the power is neither augmented nor diminishd: For let the power be in A, and the weight in C, draw the Rope in B, and the weight ascends in D.

The Demonstration. Forces of Powers are neither diminishd nor increased by an Engin, when the motion of the power is equal to the motion of the weight, but in this case it thus happens; for when the Rope A EFG C, is the same by supposition, as the Rope B EFG D, they will be equal, and the common segment A EFG D being taken away, there remains DC equal to AB; but AB is the motion of the power, and DC the motion of the weight, therefore the motion of the power, and of the weight are equal, and therefore the forces of the power are neither increas'd nor decreas'd, which was to be demonstrated.

PROPOS. VI.

A Theorem.

A Weight hung to a movable Pully its half part is Diminished.

Fig. 73. **L** Et the Pully be A, and its Snatch-block movable, and a weight hung to it, and the power in D; I say, the weight will be lessened an half part, suppose the power to be so moved, that the Pully A ascend to E. The

The Demonstration. That the Pulley A be placed in E, the power ought to be moved as much as the length of the Chords C F, G D, for from the point C to D, is the same distance as between F and G; but C F, G D taken together, are double the space A E, to which the motion of the weight B is equal as appears, therefore the motion of the power is double the motion of the weight; but (by the first principle of Mechanicks) as often as the motion of the power is double the motion of the weight, the whole force of the power is doubled; therefore in our case the force of the power is doubled in order to such weight, or which is the same, the weight is diminished an half part, which was to be demonstrated.

But if in stead of the Hook C, there be added one power which shall be equally moved with the power D, we shall find by tryal only an half part of the weight, in the same manner as if they bore two weights equally distant, hung to a Beam or Leaver.

PROPOS. VII.

A Theorem.

A Power applied to a moveable Pulley, diminishes an half part, in respect of a Weight hung on one end of a Rope.

Fig. 74. **I**F in stead of the weight B being hung, a power be applied to the same Pulley, and the weight hung to the Rope D, I say, the force of the Power is diminished an half part.

The Demonstration. As I shewed before, the motion of the weight will be double the motion of the power, and therefore (by the first principle of Mechanicks) the forces of the power are lessened, and the forces of the weight increased; which may likewise be said of two weights, to wit, as when the weight B of 100 pounds is made in *equilibrio* in the point D, or which way soever the Rope G D shall require 50 pounds.

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Corollary.

Hence it follows, that an immovable Pulley is a Leaver of the first kind, of equal Armes, and a movable one is a Leaver of the second kind, or in like manner of the third kind, of equal Armes.

P R O P O S. VIII.

A Theorem.

If to move the Wheels of a Dial, or Clock, for 12 Hours, there be required a weight of 50 pounds, and the weight descend 20 feet, keeping the same descent, a weight that shall move the Clock 24 Hours will require to be 100 pounds.

THis proposition which may easily be deduced by the Corollary of the precedent proposition, because of the commonness of its use, may be proposed in this manner; suppose a common Clock that requires a weight of 50 pounds to keep it in motion, and suppose the place where the weight descends to be 20 foot only, and this descent serves for 12 hours; and we would, keeping the same descent, have a weight to serve for 24 hours, I desire the magnitude of the weight; I say, the weight required must be 100 pounds.

The Demon. Suppose the motion of the Clock and its resistance, to be after the manner of the motion of the other weight, 'tis certain by the supposition that the resistance of the Clock for 12 hours, is less than of a weight of 50 pounds being movable 20 feet; but the motion of the Clock for 24 hours is double of that which is made in 12 hours, and in like manner a weight of 100 pounds as movable 20 feet, is double of a weight of 50 pounds that moves the same space, therefore the motion of the Clock for 24 hours will be less than a weight of 100 pounds moving 20 feet, and will be exceeded by the same excess.

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And the way to fit that weight is easie, for if it be required precisely to move in a time double to that wherein it did move, it may be done with no charge by help of a Pulley, in that manner as is shewn in the 7th Proposition, *viz.* If the Rope be fastned firmly at one end, and the other end join close to the Cylinder of the Clock.

But if another less proportion be required, to wit, as 2 to 3, or as 3 to 4, the Diameter of the Cylinder on which the Rope goes about in the Clock must be lessened, according to the proportion given reciprocally, that is, if for example it be required, that the weight of the Clock should move 18 hours, when before it moved only 12 hours, the Cylinder must be lessened according to $\frac{1}{3}$ part of its Diameter; but if there be required a quadruple proportion, two movable Pulleys must be made use of. Lastly, If a proportion much greater be required, add one Wheel to the Clock.

PROPOS. IX.

A Theorem.

In Dispaſto, or two Pulleys, if the cord of a movable Pulley be only turned about the Wheel, and is not fastned to its Snatch-block, or weight, but to the immovable point, the power will be only doubled, which draws by the other end.

Fig. 75. **B**Ecause there are many ways which Ropes may be put about Pulleys, from whence follow several augmentations of a power; I will undertake to explain this in the first place, to wit, if one end of the Rope A D C E be fastned in the unmovable point A, or to any other point, as the point B, and be turn'd about the Pulley D, then about the Pulley C, and be drawn by the end E; I say, the force of the power placed in E, with respect to the weight hanging at D, is doubled.

The Demonstration. The point E is equally moved with the point

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point F (by the first of this) but the point F is moved with a double velocity to the weight hung in D, (by the 7) therefore the point E is moved doubly swifter than the weight D; but E is the place of the power, therefore the power is moved doubly swifter than the weight, and (by the first principle of Mechanicks) the force of the power E is doubled: Which was to be shewn.

Secondly, Let the end E be firmly fixt, or unmovable in the point E, and draw the Rope upward from the power placed in the point A; I say, in like manner the force of the power is doubled, and the Pulley C is usefess.

The Demonstration. When the Segment of the Rope E C F in this case is immovable, it will be the same as if the Rope were fastned in the point F, and one Pulley used only, but (by the 6th of this) one Pulley placed in this manner, doubles the force of the power, therefore also in this case, the forces of the power are doubled: Which was to be shewn.

Corollary.

Hence it follows, that if the power be D, and the weight in E, the end of the Rope fixt in the point A; I say, that in this case, when the motion of the weight is doubled, the force of the power is lessened.

PROPOS. X.

A Theorem.

In Dispaſto, or two Pulleys, if the end of the Rope be fastened to the movable Snatch-block, and the rope be turned about the same wheel, the power will tripled, or threefold.

Fig. 75. **L** Et the end of the rope be fastened in the point I of the movable Snatch-block, then turn it about the wheel of the immovable Snatch-block B; and again, turn

it about the wheel of the movable Snatch-block I, and let the power be in the point C, drawing the rope upwards. I say, the force of the power is tripled.

The Demonstration. Suppose the power C so to be moved, that the Pulley I, touch the Pulley B; In this case there is left only so much of the rope as is required to compass both the wheels, to wit, as much as the portion F B E, and G H I, and the motion of the drawing power from C is equal to the rest of the rope, or to the parts A E, F G, H C; but those parts taken together, are triple the motion of the weight, to wit, the line I E, therefore the motion of the power is triple the motion of the weight, therefore the forces of the power are tripled: Which was to be shewn.

PROPOS. XI.

A Theorem.

In Tripasto, or three Pulleys. If two Pulleys are immovable, and one only movable, the power is tripled.

Fig. 76. **L** Et there be three Pulleys, wherein two of them A and B are immovable, or immovable in the Snatch-blocks, and let the rope be fastned in the point C; then turn the rope about each wheel, as you see in the figure, and let the weight be D, and the power in E: I say, the power is tripled.

The Demonstration. The point E is not more moved than the point F, and therefore the Pulley B is only used for convenience sake. But the point F (by the 10th of this) is moved triply, or threefold swifter than the weight D, therefore in this disposition the power is triplicated; which was to be shewn.

But the end of the rope C could not be fastned to the upper Snatch-block, otherwise one of the upper Pulleys would have been useless.

P R O P O S. XII.

A Theorem.

In Trispasto, or three Pulleys, two of them being movable in the snatch block, quadruplicates the power.

Fig. 77. **I**F there be three Pulleys, wherein the two lower ones A B are moveable; I say, the Power in C in this case is Quadruplicated.

The Demonstration. Understand the power C to be so moved in drawing the Rope, that the Snatch-block A B, touch the Snatch block E, there remains about the Pulleys a Segment of the Rope equal to the Segments D E F, I B K, G A H; the rest are drawn by the Power, and measure the Motion of the Power: But the Segments D I, L G, F H, C K are quadruple the space L G, therefore the Motion of the Power is quadruple; which was to be shewn.

Notwithstanding, because this kind of drawing upwards is inconvenient; a Pulley should be added in the Upper Snatch-block, and then its force will be quadrupled, for the Pulley is only added for conveniency.

P R O P O S.

PROPOS. XIII.

A Theorem.

If the Lower Snatch-block be moveable, and the Power draw upwards, the Power is so many times multiplied as are the drawing of the Chords.

Fig. 77. **L**ET the Snatch-block A B be movable, and the Power C draw upwards ; or that the Proposition may be more Universal, let it draw against the immovable Snatch-block, then the Power is multiplied so many times, as there are drawings of the Chords, because then either the end of the Chord being fastned, is in the upper place, and being drawn, the pairs will be doubly more than the lower Pulleys ; but the lower Pulleys double the Power, and by the demonstration, if there be one below, there is no need of the upper one, as is shewn in Prop. 6. and the force is doubled according to the proportion of drawing. If there be two below, and one above, 'tis shewn in the precedent Proposition, that the power is quadruplicated ; and so of the rest.

PROPOS. XIV.

A Theorem.

If the lower Snatch-block be movable, and the power draw downwards, the force of the power is so many times multiplied, as there are drawing of the chords, one less.

Fig. 75. **T**IS shewn that the force of the power in F is the same as in E, but if the power be in F, and

and its force multiplied according to the number of drawings, to wit, triplicated, and in E there be added one drawing of the Chord; this drawing of the Chord, which is added, increases not the force, therefore ought not to be computed.

PROPOS. XV.

If the lower Snatch-block be movable, and the rope be fastned to the movable Snatch-block, any lower Pulley doubles the power, and renders one upper power only equal to the weight.

L Et there be any number of Pulleys in which the Snatch-block of the lower is movable, to which fasten the end of the Rope; I say, If there be one upper Pulley, the power is equal to the weight; if one be added below the force of the power is doubled, and so the power will be triplicated, but the rest of the upper ones add nothing, that is, if there be two upper ones, the power will remain tripple of it self; if another be added below, it will be quintuple, and so on, which are all demonstrated, particularly in the foregoing Propositions.

PROPOS. XVI.

If the lower Snatch-block be movable, and the rope fastned to the upper, as many Pulleys as are below, so many times the power is doubled, the upper ones serve only for conveniency.

IN any number of Pulleys in which the Rope is fastned to an immovable Snatch-block, the power is so many times doubled,

bled, as there is lower Pulleys, or in a movable Snatch-block: That is, if only one be in the movable Snatch-block, the force of the power is doubled; if two, 'tis quadrupled; if three, 'tis equal to six powers, and so on, so that no proportion ought to be had of the upper Pulleys, or of their being in an immovable Snatch-block.

The Demonstration. 'Tis shewn in Prop. VI. that 'tis so in one Pulley. In Prop. IX. 'tis shewn to be so in two Pulleys, to wit, that the power in both cases is doubled. In Prop. XII. in three, or more Pulleys 'tis the same; the like proportion may be demonstrated in others.

Whatsoever is shewn concerning the raising of weight upwards, is to be understood of any other motion, whether Horizontal, or any other, to which weights resist; also of any resistance that we undertake, to overcome by Pulleys.

Also as we compare the power with the weight, we may in like manner compare two weights between themselves; likewise if you place the power in the place of the weight, and in like manner, if the weight obtain the place of the power, the weight will be increas'd with respect to the power, or the power diminish'd, which words are all of one signification; and the moving power may obtain the place of the weight, as often as the forces are abounding; but a most swift motion is produced in a weight, which simply from a power cannot be produced without an Engin, because the power cannot move it self with so much velocity; which principle is to be understood in all Engins.

PROPOS. XVII.

To dispose Pulleys so that according to the number of the Pulleys, the power may always be increased continually in double proportion.

Fig. 78. **T**He increase of power by Pulleys hitherto treated on, seems to proceed only according to Arithmetical

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metrical proportion, so we shew in the precedent proposition, that according to the number of Pulleys placed in the moveable Snatch-block, the force of the power is doubled; now we will institute another disposition, wherein if there be only one Pulley, the force of the power will be doubled, if two, quadrupled, if three, it will be octuple, if four, the power will be equivalent to sixteen, and so of the rest.

Suppose a weight to be raised being fastned to a moveable Pulley B, and let one end of the Rope be fixt in the point G, and the other end of the same Rope reach to the Snatch-block C, in like manner let another Rope F C D be firmly fixt in F, and the other end fixt to the Snatch-block D; let there be a third Rope E D H, one end of which fasten well in the point E, and let the power be in H; I say, the power in H of it self being equal to the weight, being so disposed, is octuple of the weight.

The Demonstration. 'Tis shewn (at Prop. VI. of this) that the power in H is moved with a double velocity of the Snatch-block D, and the Snatch-block D doubly swifter than C; and C doubly swifter, or as swift again as B, therefore H is moved eight times swifter than the weight, and (by the first principle of Mechanicks) will have eight-times greater force in respect of the weight; therefore 'tis sufficient that the power be suboctuple of the weight to be in *equilibrio* with the weight,

Or it may be demonstrated by any Leaver, for a Pulley disposed in this manner, is a Leaver of the second kind, in which the weight is precisely in the middle between the power and the prop, or Centre.

PROPOS. XVIII.

A Theorem.

By Pulleys any weight may be moved by any power.

First, If the power be never so little greater than the weight, it may be moved by any Pulley that only helps the application, but if it be equal, and the Pulley disposed after the

Second manner, the weight will be more easily moved; but if the power be less, as if it be to the weight as one to eight; eight Pulleys disposed in this second manner, or eight Pulleys disposed in two Snatch-blocks, will easily overcome the whole resistance of the weight; to wit, if there be a greater proportion of the motion of the power to the motion of the weight, than of the weight to the power.

Mechanick-Powers.

OF THE

SCREW.

BOOK V.

A Screw is a Cylinder wrought in one or more solid Spires, or Helices swelling out, as appears in the figure.

Fig. 79. **A**ND the use of it is common, for 'tis put into another concave cylinder, cut in like manner into concave Spires, so that the convex Spires or Helices of the former Cylinder, fit to the concaves which are put upon them. The concave Cylinder sometimes is fixt and immoveable, and in this case, the Screw besides its circular motion, hath also a right motion, whereby the whole Cylinder goes forth. Sometimes the Screw is immovable, and the concave Cylinder is only moved, and commonly a simple Cylinder is added to the Screw, into which a handle is grafted or fixt, as in A B the handle B C is adjoyn'd, that it may be moved round more easily; hitherto Authors have recalled the Screw to the Wedge, and the Wedge to the Leaver, or to the motion of a weight on an inclined plane, as if you understand D E to be

Book V.
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be the weight, and it be moved round in the Orb, so that it ascend according to the Spire of the Screw, inclined to the Horizon, or if the Wood D E be immovable, the Screw it self being turn'd about, which is consider'd by the manner of a weight, its ascent will be by the inclined plane of the Spires of the concave Cylinder F G; but these considerations are superfluous and unprofitable, when more immediately the force of the Screw may be measured from the first principle of Machines, than by such reduction.

PROPOS. I.

A Theorem.

To explaine, and measure, the force of the Screw.

Fig. 79. **L** Et the Screw be A B, furnisht with its handle B C, for also in lesser Screws of Iron which are made use of to strain something, there is added a head furnisht with a notch or cleft, that there may be put in something of Iron, which may obtain the force of a handle; And let the power be applied in the point C, and understand one circumvolution to be made, or the circle C K L to be described in the mean while the weight ascends, from one circumvolution of the Spire to another, to wit, as much as is the line N O. An interval, or space, equal to the line N O comprehended between the two Spires, is found 100 times in the circumference C K L; I say, that it may be in *equilibrio*, there is required so much power as is only subcentuple of the weight, that is, if the weight be 100 pounds, it requires a power only equal to 1 pound.

The Demonstration. 'Tis then in *Equilibrio*, when the motion of the power is to the motion of the weight, as the weight it self is to the power, but in our case the motion of the power is centuple the motion of the weight, and the weight an hundred fold of the power it self; therefore 'tis in *Equilibrio*, whence if the power be a little greater or more than one pound it will overcome the resistance of the weight.

Corollary.

If the power be applied to the wood D E, so that it move downward by a right line, and not circular, notwithstanding it will compel the Screw to move circularly, and let the weight be in C, the power requires to be centuple of the weight to move it. But if the wood D E be moved circularly, and the weight ascend upwards in a right line with the Screw; as if you feign the weight to be B; the whole circle described by the wood would be compared with the circumference of the line N O, which measures the ascent of the weight in each circulation.

P R O P O S. II.

A Theorem.

The divers uses of single Screws.

Fig. 80. **T**HE use of single Screws are various, and for the most part they are used to strain, as appears in the 79th Figure, in which the Screw A B is fastned in the hole B, also 'tis furnisht with its Spires, but the hole C is single, and consists of no Spires; while the head of the Cylinder arrives in C, and the Screw is turned about, the woods B D, C F, will come, or meet together, and the force of the power will be increas'd according to the proportion of the circle described by the end of the handle A E, to the interval of the Spires, or Helices.

And the same effect follows whether the wood B D be made immovable, and so the wood C F, come to that, or the contrary.

The second kind is, Fig. 81. when the Screw is at one end, and the wood to which 'tis fastned, is at the other end, and is immovable, and then the power will be mixt, to wit, of the Screw and Leaver, as in this figure, if the Screw A B, be ingrafted to the wood A C, in the point A, and the piece of timber to which 'tis ingrafted be fixt in the point C; and the weight,

Book V.
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weight, or that which resists the pressing, be in the point D; C A will be a Leaver of the second kind.

And that you may measure the force of this Engin, suppose it a Wine-press, and let the beam C A be equal to a weight of 200 pounds, that is, if it lies on a parcel of Grapes, it will make the same compression as 200 pound weight will make; and let the Screw be so made, that each spire be distant from one another one inch, and the handle B E 7 feet, so that its whole circumvolution will be 22 feet, or 264 inches, and let the force of the man that presses, be equal to 100 pounds; I say, the man alone hath so much force to press the Grapes, as hath the weight of 52800 pounds; the reason is clear, for while the man runs over 22 feet, or 264 inches, the beam A descends only one inch, and the weight D, which is in the middle of the Leaver A C, is only moved half an inch, therefore the force of the power is increased, according to the proportion of 264 to $\frac{1}{2}$, or of 528 to 1; but the power is 100, therefore the force of the man, using this press, will be equivalent to 52800 pounds; which was to be shewn.

Fig. 82. The third manner will be, if you make use of 2 Screws, which are moved together, or successively after each other, and one in respect of the other, hath the proportion of a Prop, or Hypomoclion; as if the Screw A be moved, the Screw B not being moved, the point B will be the Prop, with respect to the Leaver A B, which belongs to the second kind of Leaver.

Fig. 83. To this kind of power are recalled the Vices which Iron-smiths use, likewise the Presses which Printers use, and many other Instruments, whose forces we may measure by the same principles.

PROPOS. III.

A Theorem.

Of Compounded Screws.

Fig. 84. I call that a compounded Screw, whose convex Cylinder is not ingrafted, or fitted, into its correspondent

spondent concave, but is mixt with other powers. And first, if the Helices of the Screw be fitted to a toothed wheel, 'tis call'd an infinite Screw, or moving in *infinitum*, the forces of this power are wonderful, for suppose a wheel to consist of 50 teeth, also let the Axis be A, about which the rope goes round; and let the handle B C, be to the Semidiameter of the Axis, as 4 to 1, and let the power of the man be equal to 100 pounds; I say, the man being furnisht with such an Engin, is in *Equilibrio* with a weight of 20000 pounds, and the man will be equivalent to 200 men.

The Demonstration. The handle B C ought to make 50 circumvolutions, while the wheel only performs one, because that every circumvolution of the Screw impels only one tooth: Therefore while the handle B C is turn'd round 50 times, the Tympane A is only once turn'd about; but the circulation of the handle is to the circulation of the Tympane, as 4 to 1, therefore the motion of the power applied in C, is to the motion of the weight, as 200 to 1, therefore by reciprocation, the power as of 1 pound will be in *Equilibrio* with a weight of 200 pound, or as 100 to 20000, which was to be demonstrated.

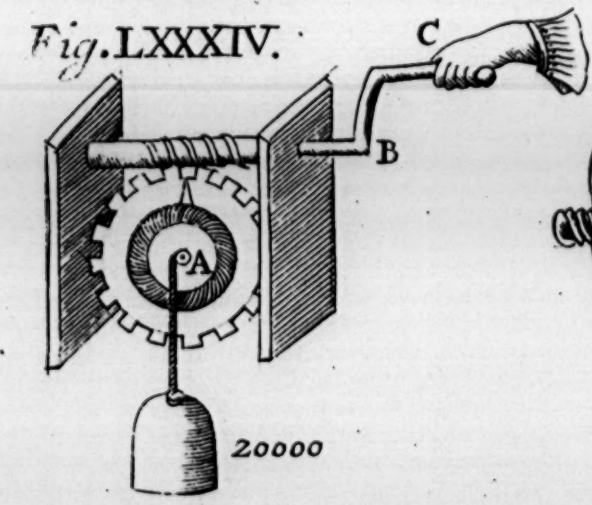
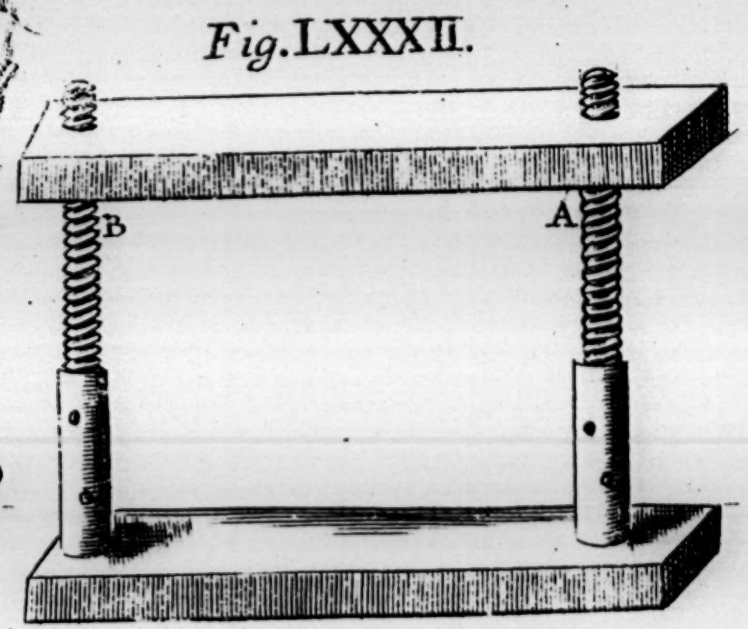
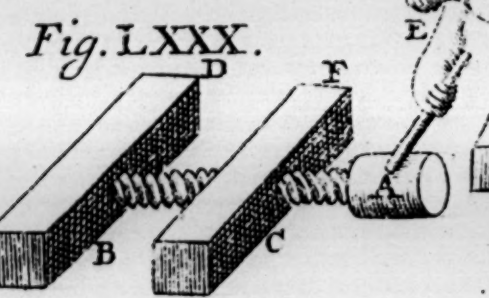
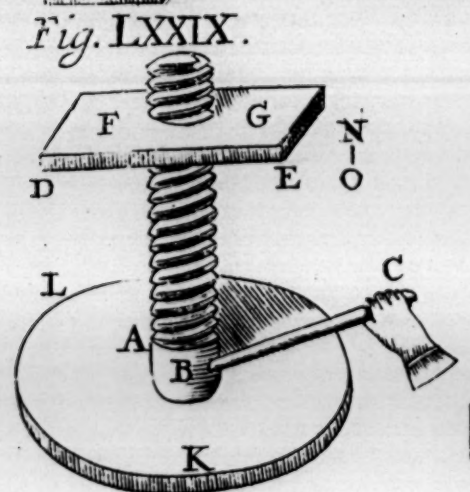
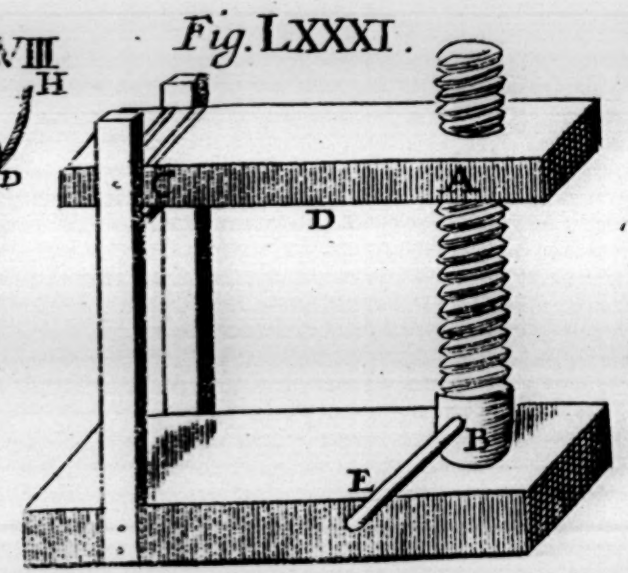
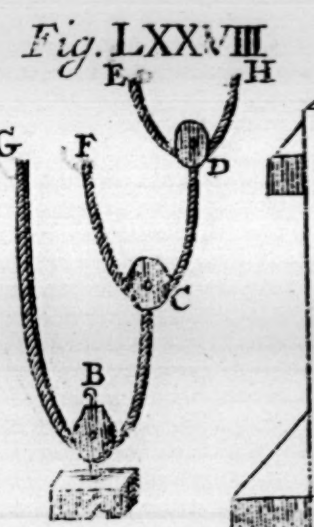
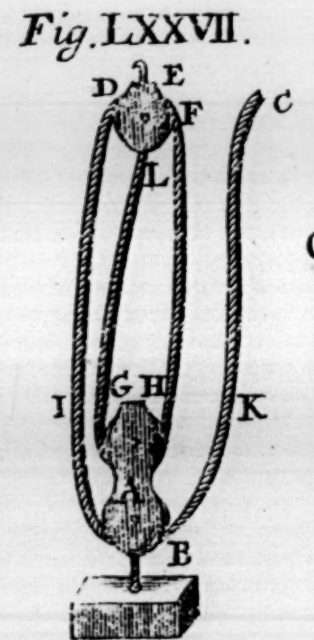
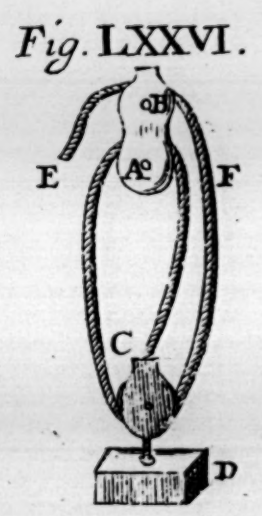
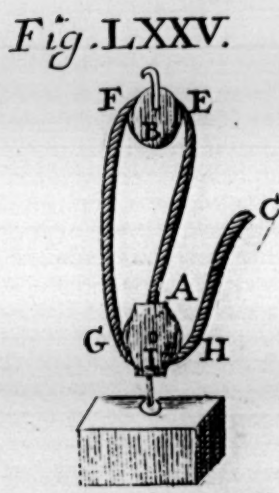
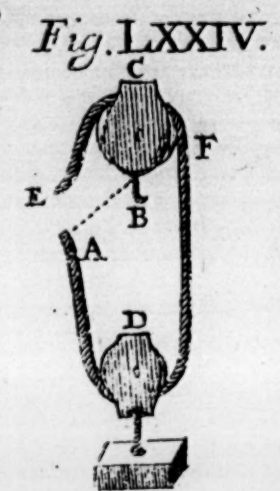
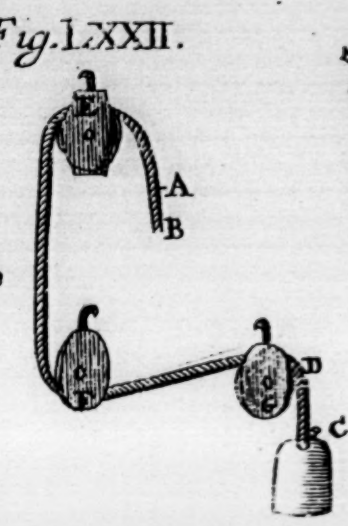
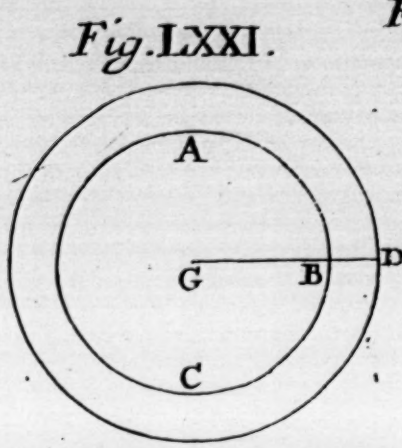
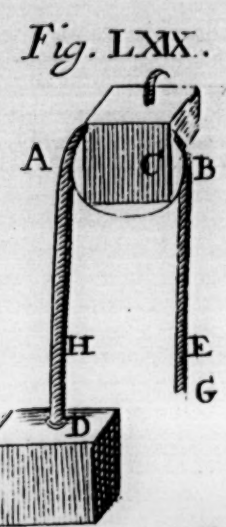
But if instead of the Tympane A, you use another Screw, to whose wheel the same number of teeth shall answer, one man will be equivalent to 10000 men. If you make use of three Screws in the same manner and order, with wheels answering to them, one man will be equivalent to 100000 men.

Nevertheless, scarce any Engins are ever made so strong, but in practice they become unuseful, because, that either the ropes break, or that which they are fastned to, is not able to sustain, or the teeth, or other parts break, the weight being so extraordinary.

This Engin is most useful, as often as the motion is to be diminisht, as when, for example, we have a wheel in a Clock, which is turn'd round once in every hour, if you desire a motion 12 times slower, the Axis of this first wheel, must have a Screw, to whose spire the teeth of the other wheel, must be ingrafted, which must have 12 teeth, and so you will have a motion 12 times slower; so if in a Clock you have a Wheel, or Axis, which is turn'd about twice in a day, which is furnisht with a Screw, and answers to a wheel, having 59 teeth,
this

And first, the wheel, 'tis the forces of the conflict of the rope goes round the diameter of the wheel, and be equal to such an Engine, and the man make 50 circles, one, because only one tooth and 50 times the circumference of the wheel, as 4 to 1 is to the man, reciprocal with a weight to be done.

another Screw, all answer, as you make use of with wheels, is to be equal to the man made so strong, that either the wheel, is not able to move, weight being in motion is to be the wheel in a Clock, you desire a wheel, must have a wheel, multiplies you will have a wheel, you have a wheel, which is far, having 59 teeth,



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this second wheel will be once turn'd about in 29 days and $\frac{1}{2}$, which is the period, or circuit, of the Moon, and so of the rest. He that desires more concerning the Screw may consult *Ubaldu*.

I speak not here concerning a concave Screw, which is one among Hydraulic Engines, and which properly belongs to an inclined plane; the benefit of a Screw are these. The first advantage is, that the motion of the weight is more diminisht by one spiral line, than by many toothed wheels. Secondly, without any stay, although the power be relinquisht, the weight scarcely falls back again, and therefore must remain where it is.

The more Helices there are in a Screw, and the more oblique, and the longer that the handle is, the easier the weight is moved; and in a concave Cylinder, (or the mother) the more Helices there are, the less the Screw suffers, for when there are many Helices, the weight is distributed in them, which would press, or lye on one only.

Fig. 85. To this Engin we may refer a certain invention obvious enough, which we do not use to increase the force of power in order to motion, but only to sustain a weight; For if about any Cylinder there be made a hollow spire about which a rope is turn'd, if you hold the rope but slightly, or press it again the Cylinder, the weight, although it be great, will be stay'd by the Ropes, being adjoin'd to the Cylinder: These Channellings, or Hollowings, are useful if any one be minded to descend from a high Tower without danger, and that swiftly, or slowly, according to pleasure.

Awgers, Wimbles, and Piercers, are referred to the Screw, which enter the easier, by being made sharp in the nature of a Screw, as experience teaches, in great Awgers, with which Pipes are boared to convey Water from Fountains, because its apex represents the figure of a Screw, which of its own accord enters the Wood so that there is but little need of Force,

Mechanick Powers.

OF THE WEDGE.

BOOK. VI.

Although the Wedge be a simple Instrument, and therefore of some, is scarcely ascribed to the number of Engins, nevertheless it is of such force, that deservedly it finds a place here.

The Wedge is a triangular Prisme, whose two rectangles, end in a common right line.

And that it may be useful, it ought to be made of solid matter, as of Iron, or Wood, and such like.

Its use is in the cleaving of Wood, parting of Stones, and dividing other bodies that may be cleft, or cloven; a slit being made in the body, the edge of the Wedge is thrust in, and a strong percussion being added, forces in the Wedge.

PROPOS. I.

A Theorem.

The force of the Wedge explained.

Fig. 86. **D**ivers reasons are alledg'd for the force of the Wedge, and first from *Aristotle*; in Question 17, the Wedge is recalled to a double Leaver of the first kind, in this manner, to wit, let the Wedge be A B C, *Aristotle* under-stands

Book VI.

stands the line is D, the point, or cusp of the Leaver, in B.

Notwithstanding the proportion of distance is of force of the power, for if the KL, and not be the same.

The second divided with part the extreme the force which is found sharper the Wedge it divides.

Whence the Wedge be a double Leaver the edge, or instances occur want a point before; so the same, touching

Fig. 87. V plane, as if the Wedge B is plane, for 'tis plane, or the same; the planes. This tend that the doctrine of inclined plane principle, may, The reason by the Wedge, the weight but compared with together.

stands the line A B, as a Leaver of the first kind, whose prop is D, the power in A, and the weight in B, to wit, in the end, or cusp of the Wedge: In like manner let B C be another Leaver, whose prop is in E, the power in C, the weight in B.

Notwithstanding, this explication is altogether contrary to the proportion of the Leaver; for by how much greater the distance is of the power from the prop, the greater is the force of the power, in other like cases; but in this case it is not so, for if the Wedge be made shorter, and the power be in K L, and not in A, nevertheless the force of the Wedge will be the same: I say, the same of the leaver C B.

The second is false, that the Wedge touches the Body to be divided with its point, or edge, because, that for the most part the extrems D and E only touch; neither when we measure the force of the Wedge, do we regard the proportion which is found between A D and D B, but how much the sharper the Wedge is, or the lesser angle it contains, the easier it divides.

Whence *Ubaldu*s in his *Mechanicks* imagines, that if the Wedge be recalled to a Leaver, 'tis to be explicated by a double Leaver of the second kind, whose common prop is in the edge, or point B, the power in A and C; but the same instances occur as before; I add moreover, that a Wedge may want a point, and nevertheless be as apt to divide as it was before; so that the inclination of the planes remains the same, touching in the points in which the body is to be cleft.

Fig. 87. Wherefore others recal the Wedge to an inclined plane, as if the body to be lifted up be A, under which the Wedge B is laid, that body being moved upon an inclined plane, for 'tis all one, whether the body be drawn upon the plane, or the plane move under it, for to ascend 'tis thought the same; therefore there are in the Wedge two inclined planes. This consideration is not absurd, nevertheless, I contend that the whole difficulty remains, to wit, that the whole doctrine of inclined planes is alike hard, labouring under the same principle, wherefore

I say, The reason why the forces of the power are increased by the Wedge, is, because the power is moved much, and the weight but little, or the greater motion of the power is compared with the lesser motion of the weight, and are joyn'd together.

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Which I shall shew, as in the *Fig. 86.* let the Wedge *A B C* be very sharp, which by one or more percussions runs into the wood, the space *B F*, in the mean while that the parts of the wood are separated from one another according to the space *D E*; if the Wedge contain an angle less than 60 degrees, *B F* will be greater than *D E*, and the power is moved according to the line *B F*, and the weight according to the line *D E*, wherefore including percussive force, which way soever, if the power simply impel the Wedge, its forces are increased, according to the proportion of the line *B F* to the line *D E*.

PROPOS. II.

The sharper the Wedges are, the greater force they add to the power.

Let there be any 2 Wedges, whereof one is more acute than the other; I say, that which is most acute, confers the greater force to the power; for by how much the motion of the power, is greater than the motion of the weight, it hath greater force in respect to that weight. But a more sharp Wedge is such, that it requires a greater motion of the power in respect to the motion of the weight, for in two triangles, having an equal base, that which hath the angle opposite to the base most acute, will have the longest side: But in the Wedge, the base measures the motion of the weight, and the side the motion of the power, therefore Wedges most acute are most powerful.

Corollary.

A Wedge whose angle is greater than an angle of 60 degrees, rather decreases than increases the force of a power.

PROPOS.

Book VI.

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 PROPOS. III.

A Theorem.

Divers kinds of Wedges.

Almost all Instruments which Artificers use to divide, or cut with, are recall'd to the Wedge, as all sort of edge tools, Swords, Pen-knives, Nails, Axes, Hatchets, are Wedges, for neither is it essential to a Wedge, that the percussion of another body be forced between the body to be divided, for it may either be simply impell'd, or from a force conceived from the leading motion to divide it; Awgers, and Piercers contain a Wedge.

Of Percussion, or Smiteing.

PROPOS. IV.

A Theorem.

Experiences of Percussion.

I Being in company, some years ago, with my Ingenious friends Mr. *Bankes*, the King's Master Carpenter, and Mr. *Morris Emmet*, the King's Master Bricklayer, since deceased, among other things that pass'd in our discourse, Mr. *Bankes* was pleas'd to say, that he thought there could be no reason given of the force of Percussion, nor no comparing the proportion of weight pressing a Nail, or such like thing, entred in a board, or Timber, to a blow smitten on the same thing. Indeed the saying was very difficult and abstruse, yet I remember I told him, that the learned and Reverend Dr. *Wallis*, a

Cassatus had writ something concerning it, and also the learned *Dechales*, whose principles I design to follow.

Aristotles 19th Question touches lightly on the force which is produced from Percussion; nevertheless, he explicates nothing further, and as I may say, only proposes a difficulty, to wit, that although a great weight be laid upon an Ax or Wedge, yet it conduces little or nothing to cleaving, but that a blow smitten with great velocity, affects much. Then he seeks how much gravity this motion adds; to the better understanding whereof, in the first place, I shall refer to experience.

The First *Experience* then shall be, that that Percussion is greatest, whose motion is swiftest, from whatsoever cause the same motion proceeds, whether it be circular, or right, 'tis little different. From whence it comes to pass, that a Hammer, or Mallet, furnisht with a longer handle, makes a stronger blow, because that power can impress a swifter motion, for if it be moved with equal velocity, whether it be furnisht with a longer or shorter handle, the percussion would be equal; also thence I think may be concluded, that lasting motion adds nothing to percussion, unless there were a disposition to swifter motion. And therefore, if the Hammer should be moved equally about some Center, it would not smite stronger after a lasting motion than after some short motion. Also 'tis clear, that when something is smote with a Staff, or a Sword, the stroke is stronger about the end, because then the staff is moved about the hand, as about a centre, whence the motion is stronger about the end, I say about the end, yet not in the end, by reason of another proportion.

Secondly, A greater body although it be moved with equal velocity, with a lesser, produces notwithstanding a stronger blow; for 'tis certain, while two bodies of the same matter, and divers magnitude fall from on high, they descend almost with equal velocity, so that the difference is very small, to wit, so much only as is begat in the resistance of the air proportionally in the lesser body to the greater, nevertheless, the greater body impresses a stronger blow, which effect cannot be only attributed to the greater gravity; for let there be a stake stuck in the ground, and let two bodies descend from an equal height, one of 100 pounds, the other of 200 pounds, 'tis certain that there will be a stronger impression from the

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Book VI.
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second, which cannot be attributed only to the gravity simply taken, for if this second body be put on the stake and gravitate on it, or should fall on it from on high, the impression from a body less heavy, would not be so much: Therefore a heavy body falling, makes a greater stroke than a lighter body, and this impression ought not to be attributed only to the greater gravity.

The Third Experience. While a body is moved about some centre for a continuance, 'tis easier stopt or stay'd if you lay hold of it by the end, than by any other part nearer the Centre, which is to be understood if it be hinder'd before the motion, or in the beginning of the motion, for if you wait till the motion be engender'd, it will be otherwise. And the reason of the first, is obtain'd from the proportion of the lever; the reason of the second ought to be, because the motion is greater in the end, and consequently a greater *impetus* is acquired.

The Fourth Experience. The strongest blow of a Sword is not about the point, nor as some think about the Centre of gravity, but between the point, and the centre of gravity; yet in general 'tis true, that a body that is moved, having the greatest part of its weight about the end, a stronger blow follows than if it proceed from one continuance, wherefore some make a little channel within the Sword, and include Mercury therein, which conveys the force of percussion to the point, and makes the stroke stronger. Perhaps, while a body is extended in one order, 'tis moved more difficultly, and therefore its velocity is not so great, and consequently its stroke not so strong.

Fig. 83. The Fifth Experience. While a body smiting descends, it causes as great a stroke, if only one part of it fall on the subjected body, as if the whole body fell on it; that is, if 2 equal bodies A and B, fall from the same height, the first whereof smites the stake C only with some part of it, but the other according to its whole lowest superficie, yet an equal stroke follows, which I have found by experience, that I might confute the opinion of some, esteeming the Air squeez'd between the 2 bodies, to confer much to the blow, yea, they will have all cutting or cleaving to be from air included within the Pores, being violently impulsed from the dividing body, for they will have air to be most sharp, and consequently most apt to divide.

P R O-

PROPOS. V.

A Theorem.

Divers measures of Percussion.

Fig. 89. **T**IS hard to measure percussion that is made by a living power, since it depends on force, and free and voluntary endeavour, and hath the proportion of the body moving, or smiting, for although a greater Hammer effects a stronger blow in other things of the like nature, yet if it be not so swiftly moved because of its heaviness, the percussion which follows is the weaker: Wherefore 'tis convenient in the first place, to reduce velocity to a certain measure.

Suppose then a Hammer A B, whose whole length is 6 feet, which is moved by a man to smite. I say, if it be moved equally with the same velocity which he hath in himself in the instant of percussion, and in the space of one second minute, shall make 4 circulations, that is 144 feet, (allowing the Periphery to be but 3 times the Diameter): If the same Hammer should fall according to the equality of the force of gravity, and acceleration of heavy bodies, it would not arrive to accomplish 144 feet in 5 second minutes, and it should fall from an altitude of 425 feet.

From whence 'tis concluded, that the altitude 425 feet is the measure of percussion made by the man, or the Hammer has so much velocity, while 'tis strongly smote, or impell'd, by the man, as the hammer would have had, if it had fallen singly from an altitude of 425 feet.

I have been willing to examine the calculation made by *Mersennus*, but could never find it answer experience, for we often use a *Pendulum* of 3 feet, one swinging, or stroke whereof is precisely equal to one second of a minute; and we have found in a *Semivibration*, or in the space of half a second, little more than 4 feet, to be past over by a body falling, viz. about 4 feet and $\frac{1}{2}$; but according to the proportion observed

Book VI.

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served by *Galileus*, it should be 17 feet in one second, wherefore in the second second it will be 51 feet, in the third second it will fall 85, in the fourth 119, in the fifth 153, which being all added together, make 425, therefore the blow of the Hammer struck by the man, is equal to that which is made by the same hammer falling 425 feet; in this supposition the space which is past over by heavy things, descending, is reckon'd to proceed according to the series of odd numbers.

But whatsoever the comparison be of the *Impetus*, or force, produced from a man smiting; and the *Impetus* produced by a weight falling; 'tis certain, that there is no *Impetus* produced from a man's smiting, to which there cannot another be given equal to it from a body falling: But hitherto the whole difficulty remains, *viz.* how we may measure the acquired *Impetus*, from a body falling from a determined height; let therefore a hammer weigh 1 pound, driving a nail at one blow (or percussion) one inch, whose force is equal to that which it would have if it fall from an altitude of 425 feet; and let it be demanded what weight being only laid upon the Nail, will force it in one inch, but that weight must be moved equal to the space, to wit, it must also be moved one inch.

Many have been the opinions concerning this thing, for suppose a hammer of 1 pound, and 1 foot long, and let it be made after the manner of a Cylinder, some think, if there should be a Cylinder made of the same thickness, *viz.* 1 foot; and 425 feet long, to wit, as much as is the altitude of the fall, which is equal to the percussion, and this Cylinder be put upon the Nail, it will force the nail into the board one inch, nevertheless, I see not on what foundation: for supposing the hammer to be half the length, and to have the same gravity; according to this consideration, it requires a weight doubly greater, which is absurd, therefore since this determination depends on the thickness of the hammer, which in this case hath no place, for neither will two hammers of divers figures, and the same gravity, have divers effects.

Others will have it, that a hammer of 100 pounds descending with one degree of velocity, will have the same force as a hammer of 1 pound, descending with a velocity as 100, which I easily grant: But hitherto I think nothing is effected,
neither

neither is there had such a measure as we require, to wit, some weight to which percussion is equal, or a weight which is moved in the same manner as a nail, although it drive it one inch.

Mr. *Hobbs* reduces all percussion to the first endeavour which the weight hath, but knows not whether the first endeavour given be indivisible and determinate, and so in this explication he wraps himself in questions of continual division.

PROPOS. VI.

The measure of Percussion.

Suppose a hammer of 1 pound, and let it be of any figure, it matters not, which being struck with the force of a man, hath the same velocity, as if it had descended 425 feet, and drove a nail one inch, now 'tis demanded what weight this percussion is equal to: And 'tis certain, that a weight of one pound falling 425 feet, acquires a force to raise 1 pound 425 feet, which I shew in any Pendulum, wherein the weight ascends almost the same as it descends. Therefore this percussion seems to be in *equilibrio* with a weight of one pound, in moving through 425 feet: But if you ask what weight being moved one inch, will be in *equilibrio* with a weight of one pound, moved 425 feet, multiply 425 by 12, it makes 5100 inches, in 425 feet; I say, if a weight of 5100 pounds be placed on the nail, the nail will be forced in one inch; for one pound moved 5100 inches, is in *equilibrio* with 5100 pounds moved one inch, wherefore the percussion of the man seems to be equal to 5100 pounds, which was to be shewn; nevertheless, there is a doubting in this calculation, because that the velocity of the weight ascending, always decreases, wherefore these things cannot be constituted, but according to the doctrine delivered of heavy bodies falling.

P R O P O S. VII.

A Theorem.

The quantity being given of a stake, or nail, driven into any body by a determined weight, from a determined height, to find a weight which will perform the same from any other height.

Fig. 90. **L** Et the weight A be 100 pounds falling from 10 feet high, and driving the nail B one inch, a weight is required, which falling from 40 feet high, will perform the same effect; I say, it requires a weight of 50 pounds.

The Demonstration. The same effect is produced, if the quantity of motion be the same in both cases: But the quantity of motion is the same, for a heavy body falling from an altitude quadruple, or fourfold, hath double velocity of that which it had: But 100 pound movable with one degree of velocity, and 50 as movable by 2 degrees of velocity, have the same parts of motion: Therefore they seem to have the same effect; nevertheless, there remains a difficulty which is begat from the reflexion of bodies, which belongs to the velocity of heavy things descending.

P R O P O S. VIII.

To make divers kinds of compound Engines.

BESIDES the single kind of Engines before mentioned, to wit, the Ballance, the Leaver, the Wheel, the Pulley, the Wedge, the Screw, there may be made many other compound Engines, some of which we will describe, that so not only their great forces may appear, but also that any one may perceive

perceive a ready way of making Engins for any occasion, and accommodate them to their use.

Mechanick Powers.

BOOK. VII.

Engin. I.

An Engin, whereby a Wagoner may raise his Wagon, or Cart, although loaded ; also by it, the Roof of an House, yea, the whole Case of the House, may be raised.

Fig. 91. **O**F Iron, or other solid matter, make 3 wheels, the 2 lesser A and C, and the other greater B ; the little wheel A hath five teeth, and the little wheel C the same ; but the wheel B hath 20 teeth, and so is fourfold greater, and hath one common axis with the wheel C, also make of the same matter a firm Prisme D E with teeth, defend on every side all the case of wood with Iron, in which the teeth are included, the upper part being open, so that the teeth of the wheel A, lay hold of the teeth of the wheel B, and the teeth of the wheel C, lay hold of the teeth of the Prisme D E : But the axis of the wheel A stands out without the side of the case, and is turn'd by the handle G F H, and with the handle the little wheel A is turn'd, which turns the wheel B and C, and the teeth of the wheel C, running into the teeth of the Prisme D E, they move it upward, until the last tooth near E, be in the region of the wheel

Book VII.
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wheel C ; if now D on the top be made hollow, or E on the side of the Case sticking out, be put under the Waggon, or other weight, and the wheels being turn'd the Prisme ascends, and going forth of the Case, forces the weight upwards ; and if the wheels are turned the contrary way, the weight descends likewise.

If to this Engin you add a leaver, one end whereof being put under the hollowing D or E, and the other end of the leaver lean, or stay on the Earth, and that part of the leaver, next the earth, be put under the Waggon, or other weight, and then turn the wheels, it will make a compound Engin much stronger, which you must note carefully, for indeed many Engins by addition of the like leaver are much helpt.

Engin. II.

To raise a vast weight with an Engin compounded of a Pulley, Axis in Peritrochio, and a perpetual Screw.

Fig. 92. **M**Ake the Cylinder C D, in the middle whereof make 4 or 5 Spires of a Screw, which while the handle E F with the Cylinder is turn'd about, the Spires infold themselves with the teeth of the wheel B, and turn it about: And while the wheel B is turn'd roun'd, the rope B G H, drawn about the Pulleys G and H, is wound about its Axis : By this means, we may with great ease raise any great weight by the power F. I have caused the like Engin to be made, by whose means, I did move a Millstone with so little resistance, that with a small Silken Thred, fastned to the handle F, and pull'd by the hand, I have turn'd about the Screw, and taken it up, being the weight of 200 pounds, and not broke the thread. And if instead of the handle E F you fit a wheel furnisht with little boards, this being turn'd about with the breath of the mouth, will raise the Mill-stone.

Engin. III.

To take up a Milstone with an Engine wrought by the Smoak of a Lamp.

Fig. 93. **T**His Engine is admirable to the Beholders, to see it raise a weight of 150 pounds; it is altogether like the precedent, but that it hath a pair of toothed wheels between the Screw A, and the Pulleys, the first of them is immediately moved by the Screw, and the second is moved by the first, and about its Axis the Rope turns round; and that the Smoak of the Lamp may supply the force of the moving power, the centre of the wheel B C is firmly put into the Axis D of the Screw, whose Teeth running in each other, are turn'd round by the Teeth of the Wheels C and B, fixt to the Axis of the wheel F G, parallel to the Horizon; this wheel is so made of a thin Iron plate tinned over, that the whole plane of the Horizontal wheel consisting of the thin plate, is cut through with Channellings, and way for the Smoak to pass, in such manner, that while the Smoak of the supposed Lamp L, passes through by the oblique openings of the plate, it turns about the wheel hung to the Glassey cover H, upon the point of a Needle, and so poised, that it may turn round easily; and if one Lamp doth not suffice, 2 or 3, or more may be added: Also there may be more wheels than the foresaid two, and more little wheels of Pulleys. My Engine which performs the foresaid effect, consists of eight Wheels and Pulleys altogether.

Engin.

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Fig. 94.

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Engin.. IV.

By whose means a mighty weight is continually raised, although the Power be not continually applied, but now and then a little impulse presses it on by it its own endeavour.

Fig. 94. **A** Apply an Iron, or Stone Globe (or Ball) of a great magnitude and weight, to a spear of Iron, or Wood C D, and let the Globe be vibrated together with the Spear about the Poles A and B; moreover let there be some pretty little arm E F L, fixt somewhere about the middle of the little Axis, or Pin K, but movable without any resistance; join to this in F a crook F G turning easily in F, let the end E, of the little Arm, be made like the point of a Sword, or Knife, (or little tongue) which may touch the Spear, being perpendicular; then that part of the Spear which touches the little tongue, must be made sharp in the same form, and extended so, that the little tongues respect and touch each other.

Then the Globe being thrust with force, or being elevated, and falling again by its weight, mightily effects the Vibrations by going and coming back, and each part of the Spear made sharp in E, hitting against the little tongue of the arm, forces the pin F G towards G, which by that means, ever and anon, lays hold on new Teeth of the Wheel H, and turns round the Wheel, which cannot be turn'd back again, being hindred by the pin P, endeavouring the contrary. Another little Wheel being annexed to the Axis of the wheel H, turns the Wheel I, about whose Axis the Rope of the Pulleys L M being turn'd, takes up the weight N, being fastned to the lowest Pulley; wherefore, if after the perpendicular stands still, and moves no longer, it be again raised from the centre and let down, its vibrations will effect in the same manner as before for some time, raising the weight in the mean while, although no power be applied, so that the weight seems to ascend of it self.

Note

Note, That you may add one or two wheels to the wheel I, that the weight may be taken up the easier, and less resist the motion of the perpendicular; moreover in stead of the Pulleys, you may use a Leaver, or a perpetual Leaver, with Axis in *Peritrochio*, &c. *Thirdly*, the longer the Spear is, and the heavier the Globe is, the longer the motion of the perpendicular endures. *Fourthly*, the upper part of the little Arm E, doth indeed endeavour downwards by its weight, but with so small endeavour, that 'tis easily moved by the Spear; the same end being but little inclined, so that a small part of the little tongue be touched by the edge of the Spear; and so also the wheel H ought to consist of small saw teeth, otherwise the force of the perpendicular will be too much allayed. *Fifthly*, 'Tis better, that only the upper part C F of the Spear be solid, and the remaining part F D be of a little chain flexible.

This Engin if it be ingeniously made, effects very well, and causes admiration in those that stand by: Besides, if the power be continually applied to the Spear, or to the perpendicular in D, which will move it of its own accord, a vast weight may be taken up with very little labour; and although the Globe D be very heavy, yet because it hangs freely, it is easily moved. In this case there is no need to make use of the little arm E F L, but 'tis sufficient that the Axis A B of the perpendicular be extended to Q, and there be fitted with a little iron hook, or catch, which may lay hold on the teeth of the wheel Q R: Or the little arm F G may be joyned to the Spear C D in E, and move the Pendulum with an opposite motion, to wit, from F towards G: But this wheel in this case ought to obtain another site than before, to wit, its plane ought to be parallel to the line of motion, which the perpendicular makes; and its teeth ought to be retain'd by the like pin, lest while 'tis free from the Clasp, or Hook Q, it return to the opposite part; likewise the whole Spear ought to be rigid, or hard. Yea, I confidently affirm, so that the spear which hath the proportion of a leaver be long enough, a vast weight may easily be taken up by one man, with only the wheel Q R, the rope being turn'd about the Axis S of the wheel, although no pulleys be added; for the leaver hath great force, although it be not in use in taking up weights, *viz.* because they know not the way whereby its motion may be continued; but we have found the precedent which is altogether

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For let the leaver be A B C, whose prop is in B, and the power in A; by weighing down, or depressing this leaver, its other end C lays hold on the teeth of the wheel D E, and moves it, the iron Pin G hindering it to go back; and at the same time the rope E F being turn'd about the Axis of the wheel takes up the weight F; but the prop B ought to be furnish'd with a ring above, in which the leaver must be put, lest it be easily moved to and fro, being only a little bent, that it may be transferred from one tooth to another below it.

Some things to be observed in the composition and use of Machines, or Engines. In the composition and use of the Engines aforesaid, and of others of the like nature, some things occur which deserve a peculiar observation.

First, 'Tis to be noted, that since in every Engin, that part which is next to the weight, feels a greater impression, or resistance of the said weight, and also ought to be more solid, firm, and strong: Example, In Axis in *Peritrochio*, or a toothed wheel and a screw, it will be convenient so to fit them together that the weight may be sustain'd immediately from the screw, and the wheels applied to the moving power; and the screw ought to be of more solid matter, and made more firm, since in toothed wheels they cannot be made so strong, as to sustain great weight.

This thing is of great moment, and therefore to be observed diligently in use, a screw, and also pulleys are wont to be applied immediately to a weight, for although a pulley seems to be less firm and strong to sustain a burden, because that the Axes of the wheels cannot be made so thick; notwithstanding each of them bears not the whole weight, even as neither any one rope that is drawn, but it is in a manner distributed to every one, so that from all, one as it were makes the resistance fit to overcome the weight.

Secondly, 'Tis to be observed, that some Engines may move a weight, or also take it up to some height, and yet notwithstanding of it self cannot move it to any further height; such are the wedge and the leaver, the first of them serving only for cleaving, but the second, if it be immediately applied to a weight, 'tis manifest that it can raise it but a little height: Wherefore as need requires, it behoves us to use divers kinds of

of Engines ; but if toothed wheels, or screws, immediately sustain a weight in the same manner that we have declared above, it acquires greater force, and will move the weight to a greater height ; also if a weight be immediately fastned to a screw, it cannot raise it to a greater height than the length of the screw : wherefore the screw hath this conveniency, that 'tis firm and fit to sustain a great weight, but cannot take up a weight very high : But on the contrary, the Pulley and Axis in *Peritrochio* can raise any weight to any height.

Thirdly, In any case which may be proposed, respect must be had to the power, together with the weight which it ought to move, that an Engin be chose which satisfies the intended end, for if the power abound, 'tis in vain to multiply, or augment the Engin, yea, with the loss of much time : For as much as the more the Engin is compounded, the more time is bestowed in the motion of the weight : On the contrary, it may happen, that such an Engin may be chose, by whose means the weight cannot be moved by the power proposed, or not without a great deal of trouble. Wherefore according to the rule shewn before (to wit, the power must be increased in the same proportion, that the velocity of the motion of the power, hath to the velocity of the motion of the weight) First, you must observe how much weight the power of it self can raise, or move, without an Engin, then from the known weight which is proposed to be moved, it will be easie to determine what kind of Engin is required ; where note, respect must be had to the proportion of the weight of the Engin, and chiefly to the resistance of it, which arises from its parts, rubbing, or wearing, against each other, for there are some Engines which make small resistance to the power, as Axis in *Peritrochio*, where there is no other rubbing or wearing, but in its two Poles ; also the leaver makes no resistance by rubbing ; but the screw because of its many spires resists much, and especially if the spires be not very smooth, and the convex, and the concave do not exactly answer each other ; in like manner the Pulley, the more wheels it consists of, the more motion it resists, because of the multiplicity of Axes, which rub, or wear the Poles.

Fourthly, Observe in any Engin, the Wedge excepted, (of which by and by) another Engin may be joyned to encrease its

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its force, so to the leaver we may apply Axis in *Peritrochio*, likewise we may add the same to the Pulley. Lastly, We increase the force of the leaver, by adding the Screw: Also the head of the leaver may be elevated by the Wedge, yea, 'tis oft-times useful to lay under the leaver a firm and solid body, then between it and the head of the leaver, the Wedge is thrust and drove in.

Fig. 95. Pulleys are not wont to be immediately applied to the leaver, for although the rope A D of the Pulleys may be fastned to the leaver C E in D, and by depressing the head of the leaver E may draw downward, notwithstanding, because this motion cannot be continued any further, therefore instead of the leaver, Axis in *Peritrochio* is wont to be used, which hath the proportion of the perpetual leaver, as is said above, for the same reason the Screw is not added to Pulleys; for although this may draw the rope a little more, yet the weight is thereby only but little raised; wherefore this artifice may be useful in case the weight were to be raised but little from the earth; lastly, the Wedge can in no wise help the Pulley being immediately applied.

The leaver may beneficially be added to the Screw, yea, without the Leaver, the Screw is not wont to move, as is observed before, it may also usefully be added to Axis in *Peritrochio*. Also the Screw may be helpt by Pulleys, but they are seldom used, and the motion is but small, as appears by consideration. But no manner of force is acquired from the Wedge, since it is not applicable to it.

The Wedge only seems not to acquire force by means of other Engins, for 'tis not moved by the force of any Pulleys, or Cranes, as other Engins are, but only by percussion: Wherefore that the Wedge may acquire greater force, it behoves to find a proportion, whereby a greater percussion appears; and this also may better be done by other Engins, to wit, if some great Iron weight made in the fashion of some Hammer, be lifted up by the Engin, and then falling by its weight on the Wedge, it forces it in; but especially by the Leaver A B, whose Prop is C; if to the end A, *Fig. 96.* there be fitted a great Iron Hammer, or Beetle, which being elevated by the turning of the wheel G from F towards E, for if the wheel be fitted with Pins, while these are born down, they hit against the end of the leaver B, and together with

that depressing, they take up the hammer A, which by its weight falling again drives the Wedge D: And the wheel G may be moved by a multiplied proportion, or by other wheels annex to the same, or by a capstand, or any other way: Commonly in Smiths Workshops 'tis moved by the force of water falling on the little boards of another greater wheel, fixt to the same Axis.

Hence it appears, by what artifice Engins are to be coupled, or join'd together, and what is to be observed in their combination, or complication, according as there is need of greater, or lesser motion, for the raising of heavier, or lighter weights.

Engin V.

Fig. 97. **T**HE Capstands, or Windlances, which obtains a vertical site are of great use, because that they may be moved only by Animals, or Cattel, which alone properly and vigorously move with an Horizontal motion; nevertheless, it hath this inconveniency, that one weight being raised up, the Engin ought to be turn'd about with a contrary motion, and so much time will be lost, while the Horse is fitted for the opposite part; therefore, to shun this inconveniency, let the Engin be composed of two windlances A B, C D; to the Horizontal one of them, fasten ropes with two Buckets (as for example) to draw water, or raise another weight, so that while one Vessel ascends full, the other may descend, you must fit to the Axis of the same windlace, two toothed wheels, or tympanes. G and H, beneath the toothed wheels, let there be another windlace C D, furnisht with another Tympane, or Horizontal wheel G H, which suppose to lay hold on the wheel G, while the weight E is raised, and the empty vessel F descends; then the weight E being raised, move forward a little the tympanes, or wheels G and H, towards B, that the tympane, or wheel G, may forsake the teeth of the wheel, and these may be implanted to the other tympane, or wheel H, which may easily be done several ways; for so the windlace A B will be turned on the opposite part,
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Fig. LXXXV.



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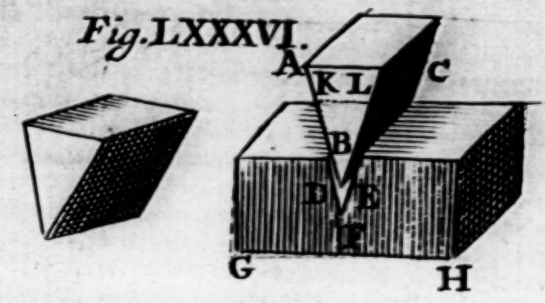


Fig. LXXXVII.

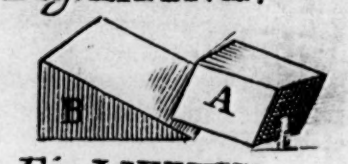


Fig. LXXXIX.

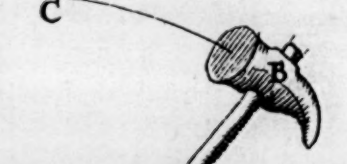


Fig. LXXXVIII.

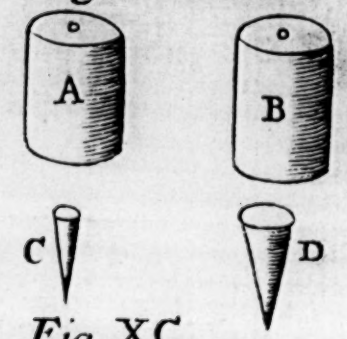


Fig. XC.

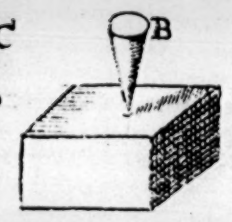


Fig. XCI.

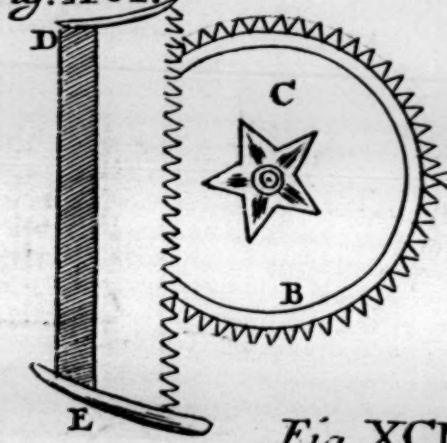


Fig. XCII.

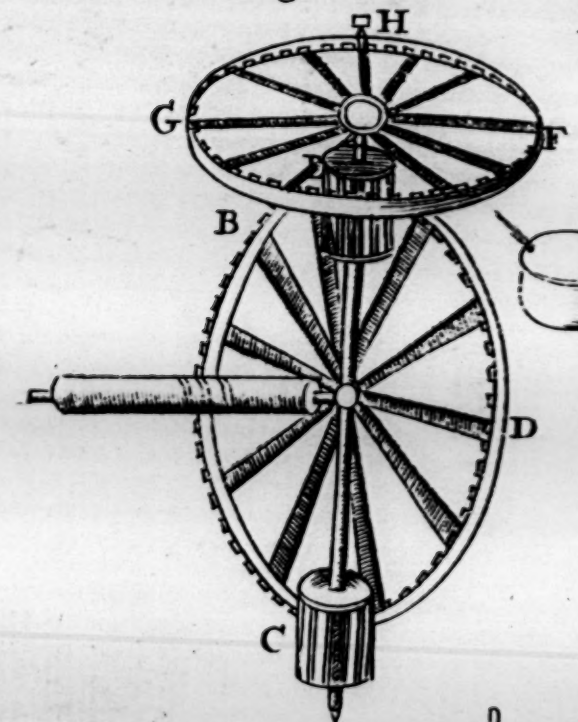
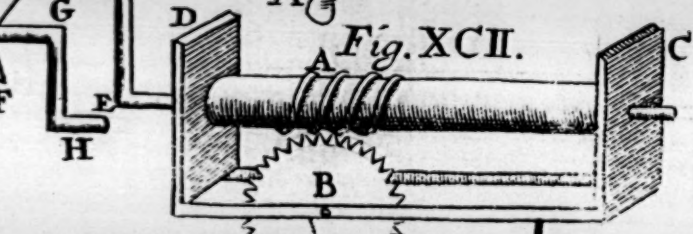


Fig. XCIV.

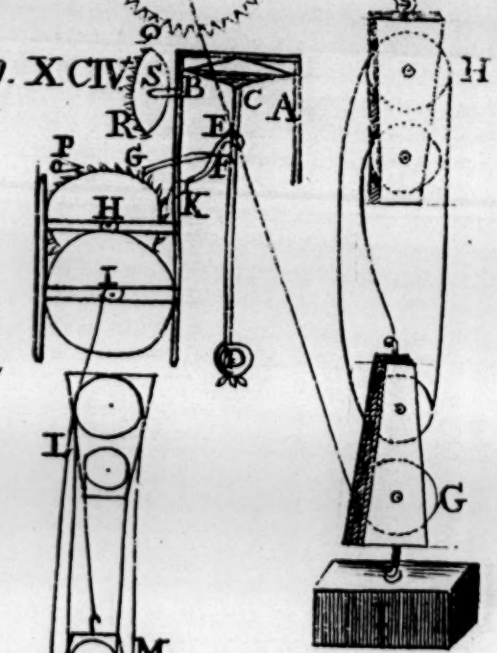


Fig. XCV.

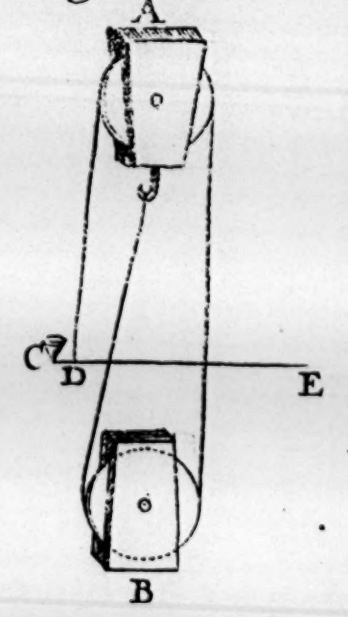
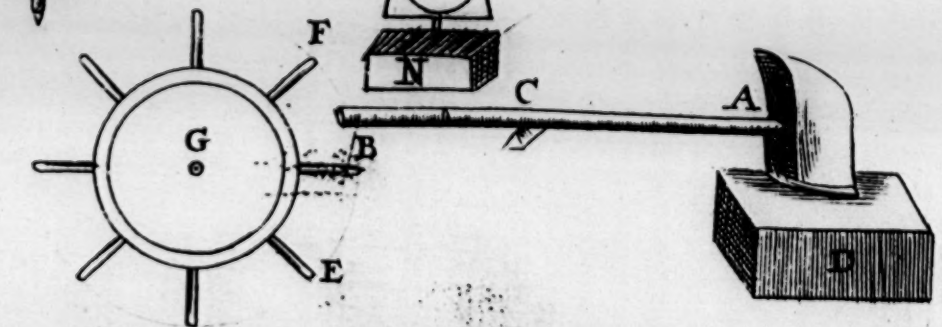
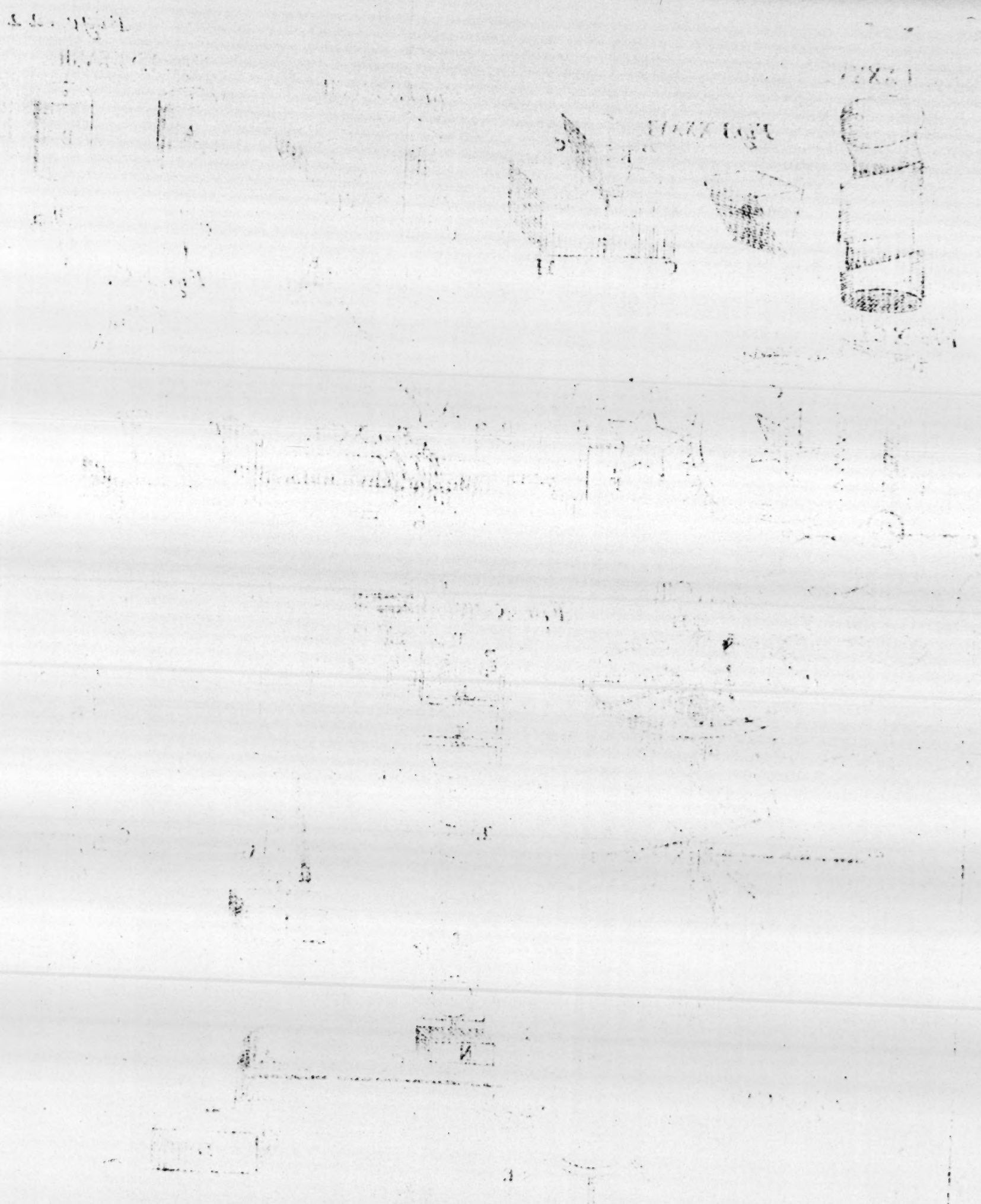


Fig. XCVI.



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and while the weight *F* ascends, the vessel *E*, being emptied in the mean time, will descend, and they will always ascend and descend alternately, or by turns; also if the power (suppose a horse) be applied to the end *I*, of the leaver *I L*, it will turn about to the same part continually.

Or the tympanes, or wheels *G H*, may easily be fitted, so that always either may be ingrafted to the opposite teeth of the same wheel *C*; but nevertheless, they must be made movable about the Axis *A B*, yet so, that by means of the Pin, or the small leaver, *N* and *M* may easily be joined with the Axis, or Windlace, as often as you please, for so by alternate force one tympane or wheel, which shall be first made firm in the Axis, by help of the leaver, resisting the moving wheels will move the windlace, and take up the weight, while the other free from the pin, will obey the moving wheels in like manner, as if it were not.

But if you would apply men to the vertical capstand, or windlace, since these are easily fitted to the contrary part, after the weight is raised, yea, they may commodiously turn about, lest they should be giddy with the motion always one way, you may fit a double vessel to draw water in the same manner, as appears in *Fig. 98*.

Moreover a windlace in a vertical site, if it be fitted either of the foresaid ways, it will much better perform the effect, than a wheel, or a crane, which many use not without danger of their lives, for if a rope, as it sometimes happens, should break, those which turn the wheel, from the great force pre-conceived, are thrown out of the wheel, which cannot happen in a vertical windlace.

This same windlace, or capstand, Seamen use, to bring in great weights into their Ships, also to draw up their Anchors; in which Engin this is to be noted, that because the Cables are so thick, that if they were many times wound about the windlace, or cylinder *A B*, in *Fig. 99*. the Engin would be rendred useless; therefore they only receive 3 or 4 Spires of the rope about the cylinder, so that while one end of it *C*, is turn'd about the windlace, the other end *D* is thrown away; and that the rope should always consist in the middle of the cylinder, the cylinder must be made in the manner of a Cone, broad, or thick in the bottom, as you see in the figure; and by this means the rope will always be kept in the middle.

Engin. VI.

To remove a Mountain, or heap of earth, from one place to another easily and quickly.

Fig. 100. **L** ET the Mountain, or Hill, or heap of Stones be A, to be removed to the place B; to save time in going and returning from one place to the other, as also, that the motion whereby the Earth, or Stones, is transferred from A to B may be swift, we may make use of the following industry: Erect at the foot of the Mountain, or in its middle, a great and solid wooden column, or piece of timber CD, and erect such another in B, viz. EF, affix at top of each piece, or column, the wheels D and F, and make hollow each wheel in the circumference; and put about them a great strong rope, extended parallel to the Horizon: But if the distance from A to B be great, lest the rope should be too much stretcht or bent, raise other such like pieces, or columns in the middle, with their wheels made hollow as aforefaid, to sustain the rope parallel to the Horizon; on the rope thus doubled, here and there hang baskets, which must be so far distant from each other, that they hinder not one another; and the ends of the pieces must be so placed, that the power applied to the leavers G and H, may be turn'd about their Centres; for so the whole Rope with the Baskets hanging on it, will be turn'd about successively: Wherefore, if men keep filling the baskets in A, and others unload them in B, the whole hill will be easily transferred from A to B.

Where Note, That the greater the wheels D and F are, the swifter the rope and baskets will be turned about: Which motion about the axis, or piece of timber being easie, may be accomplished by means of short leavers, that so the motion of the baskets may be greater than the motion of the power about the piece of the timber. Besides the saving of labour, and the gaining of time, which is effected by this Engin, it hath likewise this conveniency, that if between the two places A and B, there should be a river, or stream, or such like inaccessible,

Book VII.
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To draw Water

Fig. 101.

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accessible, as if the Earth were to be transferred from a Mound, or Hill, to the next adjoining Fields, and there were a large deep More, or Ditch, between them, you could scarcely obtain your desire any other way.

Engin. VII.

To draw Water, or Mineral matters, out of deep Wells, or Pits.

Fig. 101. **G**orge Agricola describes five divers Engins, invented and used to this end, in his 6th book of Minerals; the first 3 whereof are wrought by men, the other two are turn'd about by horses, in all of them he uses a double Bucket, or Basket, one of which being empty descends, while the other being full is raised up; in these Engins, if the Pits be deep there is this inconveniency, that when the double rope is of such length, as the depth of the Well, it is necessary that it be turn'd about every where on the Axis of the wheel, and it will take up much space on the Axis, and require the Axis to be the longer; and by how much thicker the rope is, the Axis requires to be the smaller; whence it will happen, if the Well be not broader than the whole space of the Axis, on which the rope winds about, the Buckets, or Baskets, will hit against the sides of the Well, and retard the motion; but if you make the Axis thicker, there will be fewer circumvolutions of the rope, and it will occupy a lesser part of the Axis, but then it will require a greater force of the power to raise the weight, or wheels much greater, to which the immediate power is applied; moreover, that which makes to the present thing, and is of greater moment, is, that the motion whereby the weights ascend, is for the most part very slow; wherefore we will describe this Engin, by whose help the weight is raised with a motion doubly swifter than the motion of the power. For let there be a wooden Cylinder A B, erected perpendicularly, turning easily on its poles,

poles, on whose head fit a little wheel A equipped with small cylindrical staves, being a kind of cog wheel, but in the middle let it be fitted with a leaver, or a double one C C, to which the power is to be applied: And we will suppose the power any way applied in C, the circumvolution of this Cylinder to move circularly through the circumference of six feet, so that four turnings round finishes 24 feet; and in the same time by means of the little wheel A, the wheel D E too finishes a circuit by only one turn; but the wheel F G is turned six turns, or times, and then the Axis H I is moved quadruple of the wheel G, to wit, it makes 24 turns, or circumvolutions: Wherefore, if the Cylinder I H (on which the rope whereon the baskets are fastned winds about) be of such a thickness, that in its going round, or periphery, 'tis equal to 2 feet, the basket will ascend 48 feet, viz. by a motion doubly swifter than the motion of the power applied in C.

Perhaps some may say, that so many multiplications of wheels is not necessary, if so be the same proportion, whereby the velocity of the motion of the weight increases, or of the baskets, above the velocity of the motion of the power, a greater power also ought to be applied: Wherefore, when the velocity of the weight, is greater than the velocity of the power, it may be obtained by means of one wheel only, all the rest are used in vain.

I answer, that is true indeed, in speaking Mathematically; but Physically, and in Practice the thing is otherwise, which may be seen at the first view; for if the power be applied immediately to the Radius's A, B, so that it move the Cylinder C D, with a motion doubly greater than the motion of those radius's, or of the power it-self, the power is more tired; but less, if the other wheels aforesaid come between, or being disposed in any other like manner, so that the circle which the power describes by its motion be greater: The reason whereof may be twofold, the first is, because when in this circular motion, the power being applied to the radius, the radius hath the proportion of a perpetual leaver, and the leaver as is said before, is changed in each point of the Circle, also the motion of the line of direction, (that is to say, according to which the power impresses the force to the leaver) ought continually

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to change, since it ought always to be perpendicular to the leaver; and 'tis manifest, that a power cannot exactly every moment change the direction of its force, so that any force shall be according to a tangent line of its circle, for as much as force recovers by turns, so *Impetus* impresses often times by turns, that therefore the whole *Impetus* cannot be guided to divers lines; therefore since necessarily this imperfection of *Impetus*, subsists in every animated power (of which only we are here speaking) then the motion will be the easier, where the power sustains least of this imperfection: But this imperfection is lesser, if the motion of the power be circular, or the motion of the circle be greater; if so be in a greater circle, the deflexion from a perpendicular line, or tangent, be always lesser, surely in going about, we move more easily by a greater circle, than by a less, as appears manifestly in the practice of horses going about, for as much as while they continually bend, and endeavour to make a new line of motion, they are much tired.

The second reason is, because as appears in the said Engin, *Fig. 101.* the motion of the parts of the Engin decreases, even to the wheel F, which is again moved more swift by the wheels E and D, and also effects a swifter motion in the Axis I H, and in the weight bound to the rope: For from this decrease of swiftness, even to a certain limit of the Engin, and again from a new increase, even to the end of the same Engin, and to the weight it self, it comes to pass, that the power suffers the less resistance: I say, the successive compression of the parts of the Engin, or the endeavour of the *Impetus* is propagated from the power towards the weight; and since the motion is more slow about the middle of this Engin, than in its other parts, there, after a certain manner, is the resistance of the weight gathered together, that therefore the power may suffer the less from this chiefly, because the direction of *Impetus* from the power towards the weight often-times coming unlookt for from new *Impetus's*, necessarily prosecutes its Journey towards the weight, nor cannot reflect it towards the Power.

Engin.

Fig. 101. Engin. VIII.

To apply a wheel to the precedent Engin, and to others of the like kind, by means whereof the power is eased.

BEcause the Engin last described, and all others of the like nature, for the most part require the power to be sufficiently strong, in as much as it ought to produce in the movable, a swifter motion than the motion which moves it; therefore no Industry must be omitted, whereby the power may by some means or other be helpt, or less tyred. And that will best be done by adding a wheel of some heavy matter, and altogether solid to the Engin, as if to the Axis A B of the precedent Engin, there be fastned an immovable wheel made of Stone, L N, parallel to the Horizon: For although at first sight it seems rather be an impediment, nevertheless, it appears by experience to add much to the acceleration of the motion, with less tiring of the power; for if it be exactly in *Equilibrio*, so that the Axis pass precisely through the Centre of gravity of the Stone Wheel, it will resist its circular motion little or nothing, as from what is said may be easily gathered, and as it clearly appears from what hath been said of circular motion; but from another original, whence once it hath conceived an *Impetus*, it retains it long in it self, and the more, by how much the heavier it is, so that for some space of time it will move other wheels and the weight, by only that *Impetus* conceived at first, without any new impression from the Power; whence it happens, that although the power cease for a little time from impressing a new *Impetus*, or at least doth not exert its force always uniformly, or produces an unequal *Impetus*; nevertheless the *Impetus* conceived by that wheel, ceases not to propagate further, and reduces that inequality, or deformity, to some kind of uniformity and equality, which how much 'tis in the present affair may easily be collected from what hath been said before.

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Engin in divers parts, and sundry ways ; and first, as to that which pertains to divers parts ; 'tis manifest in the Engin now described, that it may be applied either to the Axis or Cylinder A B, or to the Axis E N of the second wheel, or to the Axis F G (in which case it will have another site, or position, viz. perpendicular to the Horizon, or vertical) or lastly, it may be placed also to the Axis H I : Wherefore 'tis questionable what place it ought to be fixt, to perform the best effect. I say, then it will perform the best effect, if it be placed there were the greater force of *Impetus* is gathered together, to wit, in that part of the Engin, which ought to move most swift ; for since it better obtains its end by conceiving a greater *Impetus*, and since by reason of more gravity, 'tis capable of more *Impetus*, 'tis plain that it must be placed there, where the greatest *Impetus* is conceived : From hence it is that in the Engin described above, 'tis better placed in the Axis I H, than in the Axis G F, because that is moved swiftest : And better in the Axis G F, than in the Axis A B, because while the Axis G F, is turn'd round six times, the Axis A B is turned only 4 times ; Lastly, 'tis better placed in the Axis A B, than in the Axis E N, since this is turned slowest of all. But when 'tis placed in Engins, whose parts the further they are from the power, are moved slower and slower as some are, this wheel will be more conveniently placed to the first part of the Engin, to which the power is immediately applied. But contrariwise in those Engins in which the motion is swifter, the more the parts are distant from the Power, the wheel must be fitted to hindmost parts, agreeing with the more remote parts from the power.

Also observe, wheresoever the foresaid wheel is placed, it ought to be the more heavy, by how much slower it ought to move ; but if it be placed where it moves swiftly, a less proportion of weight will serve : For as much as it appears from the doctrine of circular motion, that the heaviest wheels maintain the imprest *Impetus* longest, although they are moved slower than the wheels that are lighter, which lighter wheels, if an equal *Impetus* be imprest they move swifter, but sooner part with or loose the *Impetus*.

Moreover, I observe, and I propose it as a new invention in this matter of great moment, that 'tis possible by means of this wheel, to promote the celerity of the motion much i

the movable, or thing moved, but adds but little to the power.

Fig. 103. For let the Power be applied in H, which moves the Axis A B, and by that means the wheel B C, the wheel D, and at last by the help of this, the little wheel E, with the axis E I, to which the rope is fastned, and turn'd about, that takes up the weight, or for any other use. In this Engin you see the motion always accelerated from the power towards the weight, or the Extream part of the Engin E I: If therefore there be ingrafted to the Axis E I, a wheel of an indifferent weight, but yet large as F G, this from what hath been said will notably promote the Celerity of the motion, so that the same power may be effect a swifter motion, using only the same power with this wheel than without it: Now therefore, since the *Impetus* once conceived, may easily be continued by this wheel, some power being added immediately to it, which either continually, or at least now and then, and often will renew that conceived *Impetus*: Example, a rivulet of water falling from on high, on the little boards, or rather bucket of this wheel, it will come to pass, that how little soever this impulse be, while 'tis in a manner continual, or at least often, notwithstanding being added to the impulse already conceived from the great wheel to this wheel, and so also to the movable, it effects the Celerity.

Secondly, The foresaid wheel may be placed either in a perpendicular axis, so that it may obtain an Horizontal site, as is seen in the foregoing Figure, or in an Horizontal axis, so that it may obtain a vertical site or perpendicular to the Horizon, as in the present Figure: And although in order to motion, the facility differs little, which way of the two you place it; notwithstanding, I esteem it more necessary to be placed in a vertical site, because, when in this case, the axis to which 'tis applied necessarily ought to be Horizontal, the weight itself of the wheel lies on two Poles, and so being divided between two, each Pole suffers less compression, and the resistance is less which arises from the wearing, or rubbing of the same Poles: But if it be placed on a perpendicular axis, the whole weight of the wheel lies on one Pole, viz. the lowest, it may seem to retard the motion of the other wheels: Nevertheless, because that very often the motion of the axis is wont to be made in a perpendicular site, bearing on the middle.

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middle part of the lower Pole, they sharpen it so, that the whole weight is born on a small part of the Cavity, that, as I have said, therefore, the wheel may move the others with more ease.

Lastly, The same wheel, of which we are speaking, may be used doubly in a vertical site: First, so that it stand wholly hang'd up in the air, and equilibrated, as in the preceeding Engin. Secondly, So that it insist or stand on the subjected pavement, and turn'd about upon it; in which case it hath also more force, than if it were suspended wholly in some axis: But the Pavement ought to be made level and plain, and solid, as of polisht marble, or such like matter, and the circumference of the wheel, which immediately touches the pavement, ought to be exactly turned, that no impediment retard the motion. So the wheel A B being applied to the extream part of the leaver C D, to which *Fig. 104.* leaver in like manner, apply a power moving the Cylinder, or Axis D E, and by this means, the wheel E, and oftentimes other wheels, for while the Cylinder is turned about by the Leaver, the Wheel A B, roles about its Leaver, leaning on the pavement, and from a double motion, to wit, one about its centre, or about the Leaver C D, which is instead of an Axis, and the other about the Cylinder D E, while it runs out from B to F, &c. And in this manner, it may be applied almost to all Engins, but especially, to those with which we use to move great weights. And the greater this Wheel is, the better it performs the effect, so that the weight be in proportion to the power applied.

Engin. IX.

To raise the Water of a Fountain always flowing, to any height, by a voluntary motion, although the height be greater than that to which the Water descends.

Fig. 105. **T**His Invention, if you entertain the perpetual motion, easily secures to it self the chiefest place: For 'tis easie to draw Water by a voluntary motion, to a greater height than is that from whence the Water of the same fountain descends, as is manifest in Spiritual Engins, but to give it a continual motion, that it shall never require the hand of a man, this without doubt deserves great praise.

This Engin contains two buckets, filling them from the fountain, of which while one ascends the other descends continually, without any labour, and serves the Water for Domestic use; therefore to make the Water ascend to a space doubly greater, than is the space of the Water descending, it must be disposed in this manner, as is represented in the Scheme.

A, Is a Vessel, or lesser Bucket which ascendeth, this being full, weighs less than the Bucket *M* being full, which descends; but being empty that weighs more than this when empty; Hence 'tis, that while both are filled together from the vessel *S*, the Bucket *M* descends, and by its weight draws the Bucket *A* up: But on the contrary, while both together are emptied, the Bucket *A* descends, and by its weight draws up the Bucket *M*.

B, Flaps to keep the Water in, tyed with a string to the leaver *D*, this leaver *D* turning easily about the Axis *C* crosswise, while the Bucket is raised up on high, hits against the piece of timber *Z Z*, and opens the flap *B*, and gives way for the Water to pass through the little Pipe *E* into the Vessel *X*. The said flap *B* being somewhat large, whereby the bucket may be emptied the sooner; make the bottom somewhat hollow.

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low, lest the emptying of the Bucket any way hinder ; and anoint it with grease, that the Water may keep in the better.

C, A stick joined to the bucket a-cross, and made fast to the leaver D, which we call an axis a little before, because of its form.

D, A Leaver with a little Wheel, or a Pulley *d*, annexed to its top, the lower end of which leaver, is bound to the flap B, with a string, for this end, that while the Bucket A, ascends towards the piece Z, and hits against the Leaver, the flap is opened and the Water goes forth.

E, A little Pipe, or small Tube, joined in the bottom of the Bucket, so that it answers beneath the mouth of the hole of the flap, through it the Bucket is emptied within the vessel X, the Orifice, or Mouth, and its cavity, are not less than the hole of the flap B.

F, Rings on both sides of the Bucket, in which are ingrafted Iron threds, or chords G G.

G, Iron threds, or chords, which must be firmly extended, lest the Bucket in going and coming hit against the side, and especially while the leaver *b* hits against the piece Z.

H, A round piece of Timber, to which the said Iron Strings or Wyers are fastned, which Threds or Wyers ought to descend from the piece Z, even to the piece H altogether perpendicular, and to be distant from each other such a space, that they strain not the Rings that are fixt to the Buckets, or at least but lightly, that so the Bucket may ascend and descend freely, and without violent wearing.

I, A Rope to which the Bucket A is fastned, passing over the little wheel, or pulley K, and within the pulley L, and from thence extending to the fastned pulley K *e*, to whose top it is fastned.

K, A Pulley joined to the piece Z, which must be large for many reasons, and a hole in the middle, and let there be a small Axis passing through the hole, which will bear the weight of the Bucket and Water.

K *e*, A fixt Pulley, that is, it doth not turn about its Axis, but is immovable, or rather a fourth part of a Pulley, its Semidiameter ought to be equal to the Semidiameter of the Pulley K, that therefore the motion of the Bucket M, may remain uniform, that is, that it may remain always in the same perpendicular ; otherwise the Rope of the Bucket M, will raze against the Iron threds, or chords G G, and so the motion will be hindred.

L, Anon

L, Another Pulley, which while the rope I draws on both sides, causes the ascent of the Bucket A, to be as swift again as the descent of the Bucket M, and therefore that runs double the space in the same time as this; for which cause the weight of the Bucket M full of Water, ought to be as much more as the weight of the Bucket A being full; but on the contrary, the Bucket A, although it be lesser than the Bucket M, ought to weigh more than it, they both being empty, notwithstanding the excess ought to be indifferent, and so exact, as will suffice that the Bucket A being empty in descending, may draw up the Bucket M being empty.

M, A Vessel, or a great Bucket, which by its descent draws up another lesser A, it hath a flap B, and little pipe E in the bottom, rings F F on the sides, Iron threds or chords G G, as the former Bucket A, nevertheless, the leaver is applied in a divers manner.

N n, A leaver placed upon the Bucket M a-crofs, to whose end *n* there is annext a stick *n a*, hanging or dangling, this, while its end *a*, descending with a bucket touches the Earth, raises the leaver N *n*, and opens the flap B, of the bucket M, at the same time in which the flap B of the bucket A is opened.

O o, Two ropes fastned above to the bucket M, and below to the piece Y, or to the Earth, to the end, that M should not ascend beyond its due limits, nor A descend beyond his: 1, 2, 3, 4, &c. are leaden weights to weaken the *Impetus* of the motion in the descent, while they lye successively one after another on the earth, and lessen the weight of the bucket to which they are fastned; but in ascending while they are elevated from the earth one after another, they adjoin new weight to the same bucket; and they may be more or less, according as is necessary.

P, A piece laid athwart a little above the bucket M, having a hole in the middle, through which a rope passes freely without rubbing, to which the bucket is fastned even to the knot Q, which knot when it comes to the piece P, stays the motion of the bucket M, and hinders it, that in descending it dash not against the earth, nor the bucket A in ascending hit against the piece Z Z.

Q, The knot spoke of but now, to it may be tyed a staff a-crofs, or overthwart, which may easily be loosd and changed as need is.

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R, Another knot with a staff athwart, which must be so far distant from the former knot, as is the space of descent of the bucket M almost to the earth; this knot may execute the office of the ropes O o, if the weights 1, 2, 3, &c. be not necessary.

S, A vessel designed to receive the Water from the Fountain, it hath a flap, and a little pipe in the bottom, as have the buckets A and M, nevertheless, the little pipe ought to cast out the water from each side, and at the same time almost, to fill together the bucket A, and the bucket M; and because these buckets are of divers capacities, the said two little pipes ought to cast out an unequal quantity of water from the vessel S: This vessel must not be in the middle between the two buckets, but behind after them.

T, A leaver fastned by a string or rope, to the flap of the Vessel S to open it; on the top it hath the table *f* adjoined, that the staff V may hit securely on it, and raise the leaver.

V, A staff fixed firmly to the side of the bucket M, with a little wheel or pulley on the top; this when its pulley raises the leaver T, and opens the flap of the vessel S, while the buckets are filling, the bucket M descends, and with it the staff V, and so the leaver T is let down, and the flap of the vessel S, is shut again, until the vessels are emptied below, and above; M returns back with its arm V, and raises the leaver T again, and opens the flap of the vessel S, as before.

X, A vessel to receive the water of the bucket A: This vessel ought to be such a space beneath the piece Z, that while the leaver D hits on the piece, the little pipe E within the vessel unloads the water of the bucket A.

Y, A piece of timber, a stump, or a stone, to which the ropes O O are fastned.

Z, A piece of timber to which the pulleys K and K e are affixt; this piece of timber hath the table *b* affixt to it at right angles, on which hits the little wheel of the leaver D, and draws near to the wall, and draws the bucket A with it towards the wall, that the little pipe E may hang over the head of the vessel X; which may also be done otherwise.

This Engin which was made at Rome in the Convent of St. *Mariae de Victoria*, the lesser bucket did contain more than an whole Urn of Water (at Rome they say *un Barile*) but before while they used lesser buckets, the Engin wanted success.

Note

Note also, that the bucket A ought first to be emptied, and then the bucket M, otherwise the water as yet contain'd, by the more heavy weight, would descend with too much force, but you may obtain that by making the little pipe E of a due magnitude.

Its flaps are of matter, and form, and magnitude, that the water before they are opened, no way runs out; in the fore-said *Roman* Engin, a palm, or hands breadth was the length, and half a palm the breadth: The matter was Lead both of the little tongue, and the table, in which the hole was, and was shut by the tongue: If they are made of wood, they have not so good success.

The Pulley L hath as much diameter, as is the distance between the true Pulley K, and the fained one K_e.

The weights 1, 2, 3, 4, &c. are fastned to the ropes O O, for this end, to stop the *Impetus* of the descending bucket A; for besides the *Impetus* which always increases in heavy bodies descending, the *Impetus* likewise is too much acquired from this, that when it comes to the piece Z, the whole weight of the rope I hangs on the other part of the Pulley K, and increases the weight of the bucket M; but when after the emptying of the buckets, the bucket A being heavier than the bucket M, together with the weight of the rope, it begins to descend, and draws with it the rope I, and therefore draws to it the weight of the Rope, and takes away the same from the bucket M. Then how much more is added to one, and taken from t'other, so much the more the *Impetus* increases of the bucket A; which *Impetus* is weakned by the fore-said leaden Plummers, while they are raised from the earth successively.

Also beware, lest the ropes are made wet by rain, or by water, otherwise they will be contracted, and not retain their due length.

Lastly, 'Tis observed in the fore-said Engin. that the water is raised as high again in the bucket A, as it descends in the bucket M, by reason of the Pulley M, which doubles the rope: But if any one would have the water rise four times as high, he must add another Pulley, and another rope; in like manner by the help of three pulleys he may make the water ascend to eight times the height, &c. so that the water contain'd in the bucket M, be quadruple or octuple, of that which

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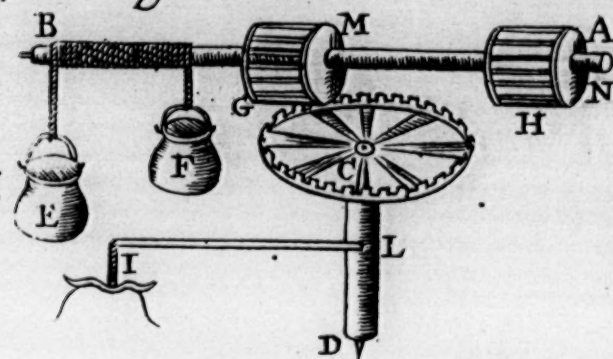


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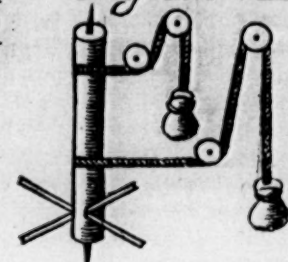


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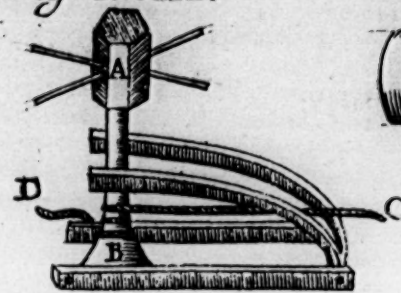


Fig. CII.

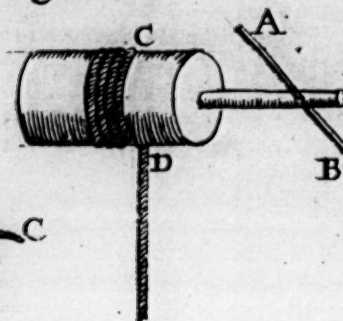


Fig. C.

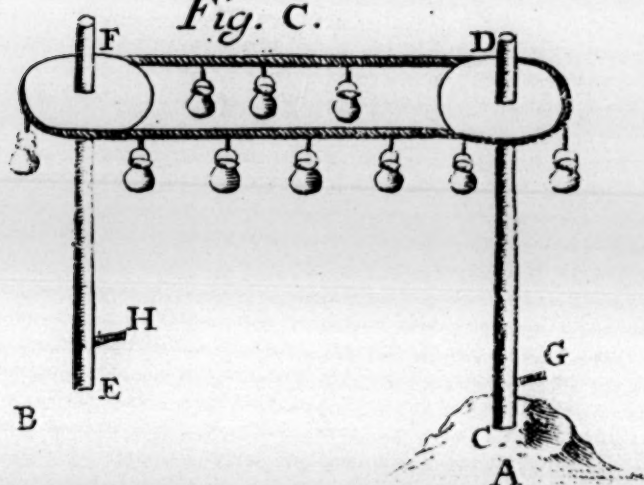


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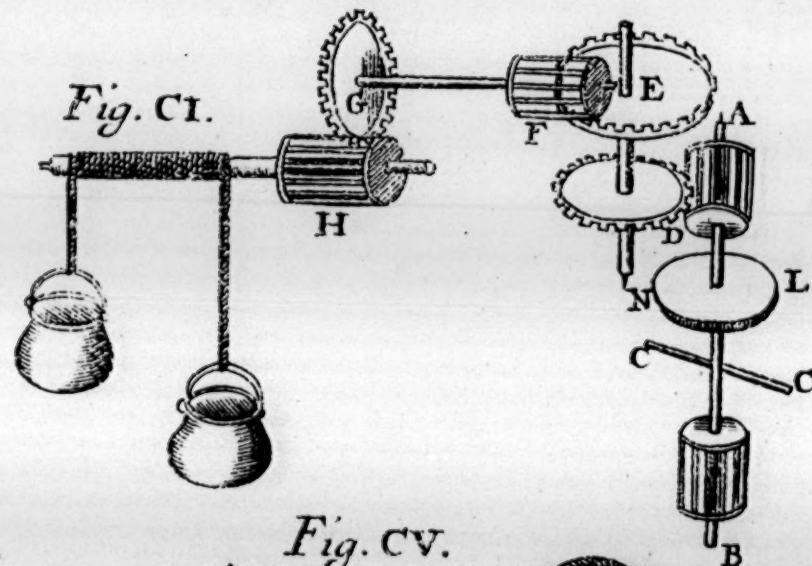


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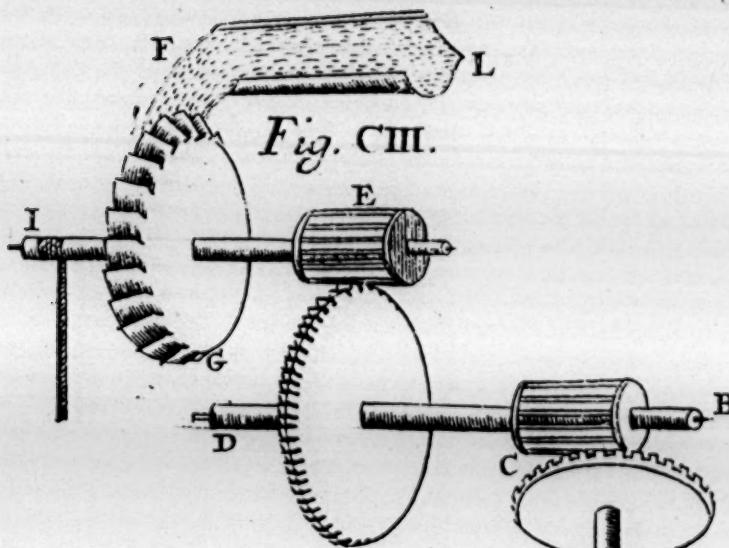


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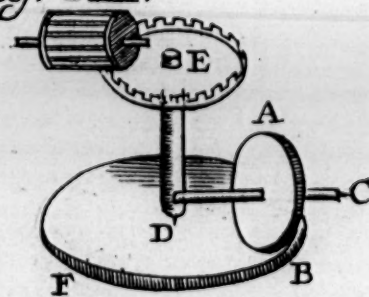
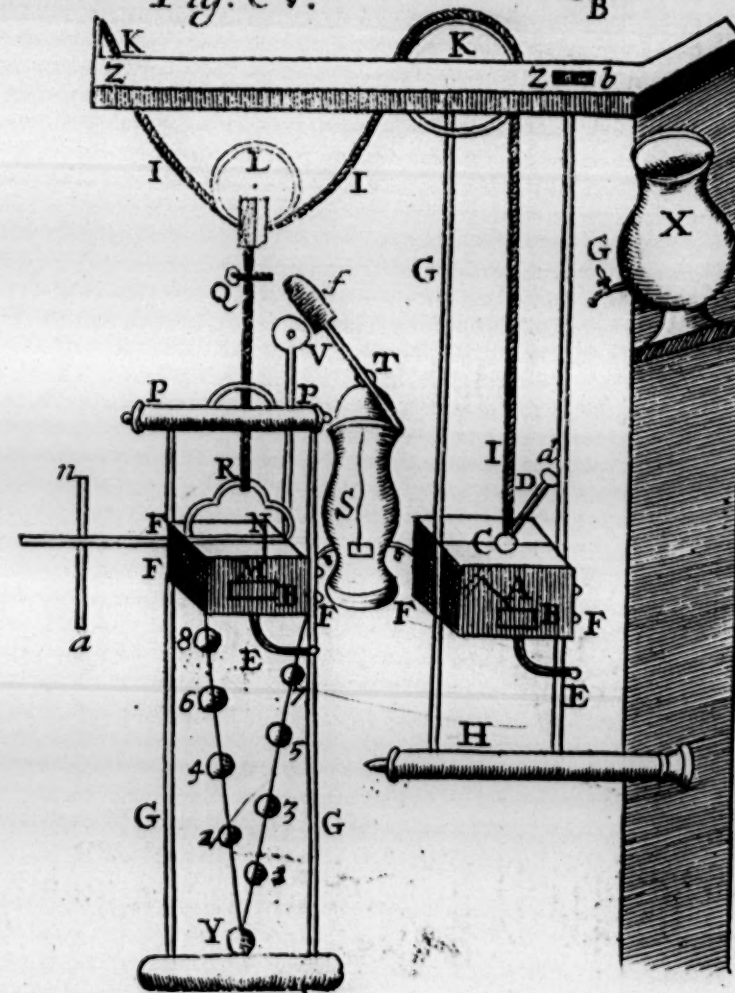


Fig. CV.



Book VII.
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is in the bucket A, yea, and somewhat more, that the bucket being full, may out-weigh the bucket A, and may draw it downwards; although the bucket A being empty, ought always to be heavier than the bucket M in like manner being empty.

Schottus in his *Technica curiosa* describes an Engin somewhat different from this; which was made at a Noble Man's House at *Basil* with good success.

Engin. X.

To perform the same thing easily in any given proportion of Height.

Fig. 106. **L** Et there be a fountain of constant Water running into the Vessel A, or at least let it be derived thither from some continual Fountain, and you would raise it to the Vessel B, whose height above A is 20 feet, but from A the water cannot descend deeper than to C, to wit, 10 feet beneath the Fountain A; nigh the Vessel B dispose the Axis D E in an Horizontal site, easily turning about the extream poles; dispose such another like Axis near the Fountain A, and annex to each of them the Tympane F, and the wheel G I; Tympanes of this kind are divided by Iron Rods, or Sticks, and of such a largeness, that there may be put upon them conveniently little Vessels, joined together by a Chain annex to one another in manner of a Ring; it matters not what fashion the little Vessels are of, so that they receive the Water easily into them, and empty the same out of them again, we have delineated two of them together in the figure L N; those which are put about the upper Tympane hang on the same, and they extend or reach along to the water of the fountain A, and are dipt into it successively, and draw the same while the Tympane is turn'd about; but when they come to the top of the wheel, they unload the same water, and pour it into the upper Vessel B. But from the water of the same fountain A, the Vessels put about the lower Tympane must first be fill'd, which ought to have a little hole open in the bottom, that the water may flow

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from the Vessel L into the lower Vessel N, and from N into another, and so successively all the Vessels of one side are fill'd; for then the weight of them and the water turn about the Tympane, together with the wheel G I of the lower Axis, which wheel running into the other, moves the upper wheel and turns it about with the Tympane of the Axis D E, that the little Vessels draw the water from the Fountain, and raise it into the Vessel B; but because the water ought to be raised double the height in B, that it descends in C, therefore the upper crown, or ring of little Vessels, ought in like manner to be as long again (or doubly longer) and therefore that it may be carried about, and raised from the lower crown, or ring, being but half so big (or doubly lesser;) those little Vessels ought to be lesser, so that they raise upward in the same manner subduple, or half the water, yea, rather less, because of the resistance of the Engin, but the lower little Vessels receive double the water, or so much as suffices to move both the Wheels.

The lower Tympane may conveniently hang over the Well, or Pit, designed for it, within which the Crown or Ring of little Vessels descending, when they come to C, the little Vessels are unloaded successively, so that one side of the Crown is always full of water, and out-weighs the other side, and turns about the Axis: That if the upper Vessel B being filled with Water, which ascends upwards, it again flows into the lower Vessel A, and the lower part of the Engin is so accommodated, that the pouring out of the Water appears not by means, whereof the lower Tympane is moved, and the Spectators may easily be deceived, thinking that Water only to descend which at once ascended, that therefore they may think it a kind of perpetual motion.

If the weight of the Water of the lower Tympane be doubly greater than the weight of Water which ascends to the upper Tympane, this Water may be raised to a double Altitude, and therefore a crown of little Vessels doubly longer must be used; and those little Vessels of the upper Tympane will be proportionally lesser in the same manner, viz. if the water be to be raised triple, or quadruple higher, the little Vessels of the upper Tympane, or wheel, must be triple, or quadruple lesser than those of the under or lower Tympane, or wheel, so that the length of the upper Crown is made amends by the magnitude of the little Vessels of the lower Crown.

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But the little Vessels of both Crowns may be made equal, and nevertheless the Water may be raised to any height, to wit, if the wheels G I which bite each other, be made unequal; for if the upper wheel hath its Diameter doubly greater than the under wheel, this will move that with a weight of water doubly less, and therefore a crown of little Vessels doubly lesser will be equal to the little Vessels of the upper Crown; I say, the same of any other proportion, triple, quadruple, &c. wherefore amends may be made divers ways for the height, and plenty of water ascending, either by means of a greater upper wheel, or by means of greater little Vessels of the lower wheel, or Tympane, or partly by means of the greater wheel, and partly of the greater small Vessels.

But if from all the Water in the Cistern A continually flowing, the greater part of it is to be raised in the upper Cistern B, as if you were to raise three parts of four of the water, and but one part only to descend, than the lower Crown must be 3 times as long as the upper Crown, and the little Vessels of the same must be at least three times lesser, if both the Axes of the wheels G and I be equal. But if the wheels G I be unequal, the proportion may be made fit another way; for if the lower wheel be three times greater than the upper wheel, the little vessels of the Crowns may be made equal, but the lower Crown ought to be three times greater; for in this case, while the lower wheel is turn'd about only once, supposing five of its little vessels to be fill'd, the upper Wheel is turn'd about thrice, and therefore fifteen of its vessels draw water, and in like manner 15 vessels of water they pour into the Cistern B.

Also both crowns, or chains, to which the little vessels are fastned, may be accommodated to one and the same upper wheel, but it will be necessary to fit to the wheel two wheels with Axes, as is declared before: But if the altitude to which the water is to be raised, be so high that it requires very great wheels, other wheels may be disposed in the middle between each wheel, which may be moved successively by the lower wheel, equally or unequally, according to the proportion of the quantity of water, or the magnitude of the little vessels; for this will be very commodious, as if the water be to ascend higher, we add to the Engin one, or more wheels, if not so high, we take away the same, making no mutation or alteration of the Crowns, or Vessels; moreover the vessels of both

crowns may be always equal, and yet the water may ascend to divers heights, the lower crown remaining the same and not altered, by only changing the magnitude of the upper crown; for as is said above, if the water ought to ascend 4 times as high as is the descent of the other, 'tis sufficient that the crown of the upper wheel be 4 times greater, or somewhat less; and the upper wheel G I, must in like manner be 4 times greater than the lower, or little more; for so the upper wheel will be moved 4 times slower, and will raise a fourth part of the water, the crowns, or chains, of both vessels being equal.

Likewise the Wheels and Axes may be multiplied together with wheels annexed, and the chains, or crown, of vessels, so that one be put upon another; for we may make another wheel to exist on the Axis D E, which may be moved by the middle wheel G I, and furnish it with a wheel, and a chain of small vessels descending into the Cistern B, and drawing water from thence; moreover that water now raised into B, may from the crown, or chain H I again be raised either all, or at least, part of it into another Receptacle, or Cistern, higher, and from this into another as high as you please, all which we leave to the will of the industrious Artificer, since we have shewn so many ways, it may suffice.

Engin XI.

To empty standing Waters.

Fig. 107. **A** is a long jagged wheel joined together with strong pieces of Timber, designed for the drawing off, or draining of water; the length may be made at pleasure, according to the proportion of the breadth of the water, also it may be made so broad; that the whole Semidiameter from the Circumference to the Axis be immerst in water, yea, the Circumference may touch the bottom, for as much as the moving force of the wheel may be increast as you please, and as need requires.

From this wheel A, the Leaver B passing through the wheel, and the water extends to the Earth, or Shoar, where is erected a wooden receptacle C. C; the wheel D is adjoined to the leaver.

Book VII.
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leaver B, which comprises the wheels E and F, and these the wheels G and H, and these the wheel I.

The leaver of the wheel I reaches to K, where it hath a strong Iron Ring put about it, which is furnisht with holes through the Circuit, and stands out towards L, that it may receive L within it.

L Q is a Cylinder, whose end L is furnisht with a like Iron Ring bored through in the Circuit, only 'tis a little lesser or straiter than the ring K, that it may be thrust within it, after that the said end L is put within the ring K, both the rings are firmly bound by Wedges and Hooks of Iron driven in through each corresponding hole, that the Cylinder L Q, together with the leaver K, may be turn'd about: In M are Wedges, and Hooks of Iron, which are join'd to the two said iron rings K and L, and made firm, that the axis K and the Cylinder L may be turn'd together; the rope that draws is folded about the Cylinder L Q, which must be lengthned that it may pass above the wheel or pully N; to the rope is hung the weight O, of as many hundred pounds as you please, or necessity requires; this weight, while the rings K and L are firmly joined, turns about the wheel I, and this the middle wheels H and G, then E and F, and at last D and B.

The weight O, how great soever it be, after that 'tis turn'd about with his rope, it may be raised again, or by a man only, it may easily be done with the Engin called *Pancratiūm* P. which that it may be done, 'tis necessary that the end Q of the Cylinder L Q be not round, but square like the end of a spit, which being turned round, the little Engins are turn'd about, and 'tis bored through that it may receive a Nail, or a Wedge, but the end of the Axis of the lowest wheel of the *Pancratiūm* ought to have a square hole which agrees with the said end Q, that this may be put into that, and fastned with a Nail, or made firm with a wedg after that manner, that a Spit is thrust into the hole of the round machine, or wheel, that turns the Spit.

Then when the weight O is drawn to, I take away the wedges and hooks M, from the rings that are conjoined to K and L, that L may be freed from K, then I apply the *Pancratiūm* to the square end Q, and turn about the handle of the *Pancratiūm*, which when done, the wheels I, H, G, &c. rest, but the weight O is raised, and the leading rope is turn'd about the Cylinder L Q.

After

After that the weight O is raised, join again and make firm one within another the rings K and L, but remove the *Pancratium* from Q, and the weight by its descent will again turn the wheels I, H, G, &c.

From whence it appears, that the chief Artifice is placed in this, that as great a weight as you please may be applied instead of a power, by means whereof while it is moved very slowly, it effects a swift motion in the extreame wheel of the Engin; and again, by applying the *Pancratium* P to the Engin, whose Fabrick is declared above.

But because perhaps it requires as much time to raise the weight O with the *Pancratium*, as is that wherein the same weight descends, and therefore great part of the Engins time is lost by this effect; therefore I advise to dispose another Axis T V upon the Axis L Q, and in the mean time while the weight O descends, and the Engin performs its effect, the same *Pancratium* being applied to the Axis T V, may raise another weight X, to be applied again presently to the Engin, as the weight O comes to the bottom, to be taken up again by the same *Pancratium*, while the wheels are turn'd about by the other weight; for so the Engin, or Machine, will never cease from motion, besides that little time wherein the rope being loos'd from the weight, is again turn'd about the Axis L Q, and the fastning it to the other weight now raised above; yea, those iron Rings and Wedges will not require to be used, if so be you can use one continued Cylinder only M L Q, to which the rope may easily be wound about, since this will be free from the weight; Or likewise a double rope may be used, one of which without weight (or at least but a little) may be wound about the Cylinder, while the other is roled and drawn downward by the weight.

This Engin if it be made after the foresaid manner, it will be indeed more simple and easie, and serve for many other uses; as for Example, the lower wheel B will easily be applied to a vertical wheel, which will likewise turn about swiftly a hand mill; in like manner there may be added to the Axis B D, pins to take up Pestles, wherewith mineral Veins may be pounded, or Gun-powder, &c. as is declared before, also there may be many other wheels to turn about to wind silver Thred, and other such like, as will appear to the Considerate.

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Book VII.

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Engin. XII.

By whose means the water always ascends to any given height, supposing also it be but a small stream of water, so it be but constant.

Fig. 108. **L** Et there be a large Receptacle, or Cistern A B, into which the water constantly flows through some Channel, or Pipe C, below that cistern make two other cisterns G H, and X Z, in two several places of sufficient bigness, according to the proportional quantity of water, which must descend by turns from the cistern A B, into those two lower cisterns, as will appear by and by, and for that cause the Tubes F G, must descend from the bottom of the cistern A B, into the cistern G H, and Y X into the cistern X Z, and these cisterns must be furnished with a cover, and the cover must come close to the side, for they ought to be every where close and shut, but the cistern A B must be open; those Tubes upon the bottom of the cistern A B, must have flaps E and D, so that their mouths may be shut or open: The cistern G H will need another Tube in its lower part, furnished likewise with the flap I, and the same must be as near as may be of the magnitude with the Tube F G and Y X; the same must be performed in the other cistern X Z, which in like manner must have the like Tube Z furnished with a flap.

Through the cover of the cistern G H, a small hole being made, descends a rod of mettall O M fitting the hole, to whose lower part the brass vessel M is soddred fast being inverted, to wit, so that the open part of the vessel, or bucket, look downwards, and to the other end of the rod O, is fastned the arm O N, which is so posited in N, that it may easily be moved upwards or downwards; to the same little arm O N is affixt such another like rod, which descends in the same manner into the lower cistern, and sustains the weight L within the cistern; finally, that little arm is furnished with a little wing *a*, hindering its coming upwards, and 'tis intercepted with a double staff, or spear, or between the notch P N, 'tis interrupted by the little arm *b* a thwart; this kind of staff, or notch, on its up-
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per part P, is fastned to another staff or leaver P Q V, and to the same leaver in Q, is knit or fastned another rod I Q R, by whose means the flap I is opened and shut: Furthermore the leaver R S T is moveable about the centre, by help whereof while the flap D is lifted up or opened, the other flap E is depressed and shut, and *vice versa*.

These things being thus disposed, that some determined part of the water which descends into the Cisterns G H and X Z, may ascend again to any given height, (as for example) into the upper cisterns A and B; above the cistern G H make another vessel, or cistern C E, yet so, that it may be somewhat lower than the superficies of the water that is in the cistern A B, and let it be close shut every where that no air enter in. Through its bottom, and through the cover of the cistern G H, let the Tube C H descend reaching almost to the bottom of the cistern G H, and almost touching the cover of the cistern C E. Then from the same vessel C E, must ascend two other Tubes into another vessel like that before, to wit, the Tube E F, which almost touches the bottom of the vessel C E, and the cover of the upper vessel D G; and the Tube C D, which ascends from the cover C of the lower vessel, almost to the cover of the upper vessel in D; altogether in the same manner, two other Tubes G A, D H, must ascend from the vessel D G, into the vessel H A. Lastly, in the uppermost vessel A H, which much be open without a cover, fit a *Scyphon* A P, through which the water is derived, or conveyed, into the cistern P Q designed for use.

Above the cistern X Z, in the same order must be placed so many, and altogether the same vessels furnisht with the same Tubes.

Then from the cistern A B, by opening the flap E F, the water flowing into the lower cistern G H being close shut, 'tis compell'd by the compressed Air to ascend through the Tube A C, into the upper vessel C E, the Air being excluded in the mean while from it by the Tube C D. But in the sametime in which the vessel C E, is fill'd with the Tube A C, its breadth being less than the breadth of the Tube F G, the water always fills the cistern G H, and forces the inverse bucket M to ascend, until at length by means of the leaver, or arm O N, hitting against the little arm b, raises the staff P N, and the same work interposing P Q V, opens the flap I, and shuts the flap Z, and likewise by means of another leaver R T S, the flap E is shut, and the flap D opened,

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pened. Then from henceforth presently the water from the cistern A B, begins to flow into the other cistern X Z, and from thence ascends and fills the upper vessel L, and at the same time by opening the flap I, the receptacle G H is emptied of all the water, and therefore the inverse bucket M descends again, and the weight L in the middle, and the wing *a* draws down again the staff P N, and shuts the flap I, and opens the flap Z; and likewise shuts the flap D, and opens the flap E, that the water may again flow into the receptacle G H; then by condensation, or pressing of the Air interposing, the water which now should ascend into the vessel C E, is forced to raise higher into the vessel D G, which being filled, they presently change turns, and the flaps Z and E are shut, and I and D are opened, and so the water ascends from the vessel L into the vessel M; this in like manner being fill'd, the flux of water is changed, and the water ascends from the vessel D G, into the uppermost vessel A H, afterwards from the vessel M, into the vessel B, while in the same time the vessel A H is emptied by the *Scyphon*, the water flowing into the common receptacle Q P; then again the vessel C E is fill'd, and after that the vessel L, and in the same order alternately new water ascends from one vessel to another, as often as the flaps change turns, being sometimes open and sometimes shut.

Where 'tis manifest, if the vessels be increased one above another, the water will be forced to any height although but slowly; and the foresaid vessels ought to be so far distant from one another, that the height of one above the other, doth not exceed the height of the receptacle, or cistern A B, above the cisterns G H, Z X, or the perpendicular altitude of the fall of the water which we conclude to be constant. Moreover the Tube C D ought to be fitted with a flap, or thin board in C, so that when the vessel C E is filled with water, the flap or board may shut it, that the air break not out through the Tube into the vessel above, for so this air being compressed, forces the water from the vessel C E to ascend into D G; I say, the same of the Tubes C D and D H, &c. also this artifice may be otherwise disposed, as shall seem meet to the industrious Artificer.

Mechanick Powers.

O F

CIRCULAR MOTION.

BOOK. VIII.

PROPOS. I.

Of mix Motion from Circular and Right, or from two or more Circular.

WHile a Wheel is moved upon a plane superficies, I say, the same of a Globe, or ball, the central point only of the Wheel, or Globe, is moved with right motion, all the other points, or parts of the moved Wheel, or Globe, are moved with a mixt motion of circular and right.

This motion of rotation on a plane hath admirable properties throughout; which being rightly perceived, it will be easy to understand the other mixt motions: Wherefore we make a beginning from it; but yet we first advise that circular motion truly and Physically consists of many right lines, nevertheless in this place we will consider it even as if it were altogether simple motion, but where it will be needful to consider those small parts of right motion of which circular motion is compounded, there we will make particular mention.

Fig. 109. Let then the Wheel, or orb, be $AZLQ$, insisting on the Plane AD on which it is to be roled, or turned, and let the right line AD be equal to the arch AQ , so that while the Wheel is moved towards D , the point Q may touch in the point D : In this motion 'tis manifest, First, that the Centre of the Wheel O is moved by the right line OE , for since the Wheel always

Book VIII.

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always touches the plane in some point, and the Centre O is always equally distant from the points of the Periphery, which successively touch the plane, the Centre O will always be in the line O E, and when Q is come to D, the Centre O will be in C, and the Centre O always insists perpendicularly on the point of Contact.

Secondly, 'tis manifest that any other point is moved with a mixt motion; for if, for example, we take the point L, over and above the motion of the centre 'tis moved towards Y, so that if the Wheel should not be turn'd about the Centre O, but only moved upon the plane, always touching the Plane A D in the point A (which is to move only by the motion of the Centre) the point L will be moved by the right line L Y, and while A is in D, E will be in Y, O will be in C, and so any other point of the Wheel will be moved by a right line parallel between the extrems A D, L Y. In like manner, the point L, or any other, will be moved only by a circular motion, if the Centre of the Wheel O be altogether immovable, to wit, L will be moved by the arch L K e, &c. A, by the arch A T, &c. also the point N will be moved by another arch of a lesser circle, &c. Since therefore the Wheel is moved together by the motion of the Centre towards E, and by the motion of the Orb from L in Q, and from Q in A, &c. the point L will be moved with a mixt motion from both, to wit, of the Centre, and of the orb, that is, of right and Circular; which may be said of any other point, the centre excepted.

P R O P O S. II.

Any point, except the Centre of the foresaid Wheel, or globe, describes a crooked line, which is not circular.

Fig. 109. **F**OR example, take the point L, and that you may get the line which it describes, divide the arch of the quadrant L Q in as many equal parts as you please, suppose three, L K, K A, H Q; also divide the line of the plane A D into so many equal parts, to wit, three, then the point L having past over the first part of the arch L K, if it were moved only by the motion of the orb, it will be in K; but

if it were moved only by the motion of the centre it would be in V, therefore let the right line MI be parallel to LY, and let KI be equal to LK, or AB, without doubt the point L will be in I; For the motion of the orb gives LK, or MK, but the motion of the Centre gives LV, or KI. In like manner, in passing over the arch KH, the same point L will be in G, if you take HG equal to AC, or LV, and parallel to LY; For the motion of the orb gives LH, or NH, and the motion of the centre gives AC, or LV, which is equal to HG. Lastly, in passing over the arch HQ, the point L will be in E, to wit, if QE be taken equal to AD, or LY, for the motion of the orb gives LQ, or OQ, and the motion of the Centre gives AD, or LY.

Secondly, take the point A, and that you may have the line which it describes, divide in like manner the arch of the quadrant AZ into 3 equal parts, to wit, in T and Y, then in passing over the arch AT, if the point A be moved only by the motion of the orb it will be in T; but if it be moved only by the motion of the Centre it will be in B, therefore if you take TS equal to AB, the point A will be in S. In like manner, in passing over the arch TY, if the point A should be moved only by the motion of the orb, it would be in Y; but if it should be moved only by the motion of the Centre, it would be in C, wherefore if you take YR equal to AC, it will be in R. Lastly, in passing over the arch YZ, it will be in P, if so be you take ZP equal to AD.

From hence it appears, that those are *Curve*, or crooked lines, and yet not circular; wherefore some call them by a proper word, *Whirling-lines*; you may call them as you please.

Also by this you see that the point L, which is opposed to the point of Contact A, is so moved, that the motion of the orb, being added to the motion of the Centre, for each motion is in the antecedent, but nevertheless the point of contact A, is so moved that the motion of the orb is taken away from the motion of the Centre; for the motion of the Centre is in the antecedent, but the motion of the orb is in the Consequent, notwithstanding because the motion of the Centre, is greater than the motion of the orb; it follows, that the point A Simply and absolutely will be moved in the antecedent, to wit, towards D, neither will it wholly go back; to wit, it will be moved towards D, only so much as is the difference XS, be-

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tween the motion of the orb A T or K T, and the motion of the Centre A B or S T.

Also take notice that the point L descending in the arch L Q, will be so moved that the motion of the orb adds to the motion of the Centre, the right lines of the arches it passes over. So the motion of the orb L K, adds the right line M K, to the motion of the Centre K I or L V; and the motion of the orb L H adds the right line N H, to the motion of the Centre H G or L V, &c. But nevertheless the point A opposite to the point L, to wit, the point of Contact with the plane is so moved in the arch A Z, that the motion of the orb takes away the right lines of the motion of the Centre, so the motion of the orb A T, takes away the line T X from the motion of the Centre T S or A B, to which T S is equal. But now the point Z is so moved through the arch Z L in ascending, that the motion of the orb adds the versed lines to the motion of the Centre; thus the motion of the orb of the arch Z d, adds the versed line Z e, to the motion of the Centre D F, wherefore if you take D f equal to A B, the point Z in passing over the arch Z d will be in f, likewise in passing over the arch Z b, it will be in g, for the motion of the orb adds the versed line Z m, to the motion of the Centre A C, equal to which b g being taken, and in running through in the arch Z L, will be in Y, for the motion of the orb adds the versed line H O to the motion of the Centre L Y; moreover the opposite point Q so descends through the arch Q A, that the motion of the orb takes away the versed lines from the motion of the Centre; so in passing over the arch Q n, the versed line Q t, is taken away from n r, which is put equal to the motion of the Centre A B, and so the point Q will be in r; but in passing over in the arch Q p, the point Q will be in B, to wit, p b being taken equal to the motion of the Centre A C, for it takes away the versed line Q i; Lastly, in passing over the arch Q A it will be in D, and so the versed line Q O will be taken away from the motion of the centre A D.

Hence you easily see the description of lines, which each point of a circle runs over being roled, or turned, on a plane. Also you see the line which the point L describes in descending, that is to answer the line L I G E, and is equal to the line Z t g Y, described from the point Z in ascending; and the line A S R P described from the point A, answers, and is equal to the line Q r b D. described

described from the point Q, that ascending, but this descending.

Hence also it is that the points L and Z are moved most swift, but the points A and Q most slow; and the point L is moved Swiftest of all in the beginning, afterwards more slowly: But the point Z by inverse proportion is moved slowly in the beginning, and successively more swift. In like manner the point A is moved slowest of all in the beginning, afterwards successively more swift, but the point Q by inverse proportion is moved more swift in the beginning, and in the end most slow. Wherefore all the points indeed are moved with unequal motion, while they run over the quadrant; but the whole quadrant being compleated, the motion of the point L, and of the point Z come to be equal, so also the motion of the point A and of the point Q.

Moreover you see the Centre O to be moved swifter in the beginning than the point of Contact A, but in the end more slow, and the space which the point O dispatches from O in C, is greater than the space which the point A dispatches from A in P.

Also you see that no point is moved with an equal motion, except the Centre, but by an accelerated or a retarded motion; so that from two opposite points one is moved with an accelerate, motion, as the point A, but the other with a retarded motion, as the point L.

At length if you take the point B 45 degrees, that is, which dispatches the greatest space of all, for the motion of the Centre O S equal to A D, is added to the motion of the orb from B in Q.

Fig. 110. Thirdly take a point within the Circumference, suppose the point F: And that you may find the line which it describes, make the Circle F 4, G 9, and divide the quadrant F 4 into 3 equal parts marked in the points 2, 3. Then while the motion of the orb comes to 2, the motion of the centre A B or 2, 5 is added to the sine 2, 1 of the arch F 2: In like manner while the motion of the orb comes to 3, the motion of the centre A C, or 3, 6, is added to the right sine H 3. Lastly while the motion of the orb dispatches the quadrant F 4 and comes to 4, the motion of the Centre Q 7, is added to the right sine Q O, and describes the line F 5, 6, 7: In like manner, by what hath been said, you may easily find the other lines

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lines which the other points of the same lesser circle contain'd within the greater describe. So the point 4 describes the line 4 M N P, while the versed line 4 R is taken from the motion of the Centre A B or L M; and the line 4, 5, from the motion of the Centre A C or T N; and lastly the versed line 4 O from the motion of the Centre A D or G P.

P R O P O S. III.

A lesser Wheel included in a greater is so moved, that in it the motion of the Centre is greater than the motion of the Orb.

FOR while the motion of the Orb is made through the whole quadrant F 4, the motion of the Centre is made through the whole right line O V, which certainly is greater than the arch of the quadrant F 4. In like manner the motion of the orb through the quadrant 4 G, is less than the same motion of the Centre O V; But how each point of the quadrant 4 G answers each point of the plane G P, upon which the quadrant of the lesser wheel is understood to move, when the plane is greater than the quadrant, is that famous difficulty which obtains the name of *Aristotle's Wheel*, because *Aristotle* hath proposed it in his 24th. question of *Mechanicks*, which *Blancanus* hath explicated, and *Mersennus*, *Galileus*, *Cabens*, *Fabrus*, and others have exposed to view.

P R O P O S. IV.

The difficulty of Aristotle's Wheel, that is, the motion of the lesser Wheel when this is directed by the motion of the greater, and the motion of the greater; when this is directed by the lesser, is best solved and unfolded from the nature of this Circular motion, so far as Physically 'tis compounded of many right lines.

LET the Wheel be A C H insisting on the plane C E, whose radius is A C, and within this another lesser, suppose it subduple, A D B is included, whose radius is A B; and let the plane

plane CE be equal to the arch of the quadrant CH , so that while it is turned upon the plane CE , each point of the arch answers each point of the plane; When therefore the lesser Wheel in this motion is carried away by force by the greater, surely the point D will come to F , when the point A will come to G , that is, the radius AD will meet with GF .

Therefore the whole difficulty will depend on this issue, that BF will be double the arch BD , if so be the points of the arch BD ought successively to correspond with the points of the plane, or of the line BF , or each point of the arch BD answers each point of BF , or each point of BC answers two of BF , or the altern points BF by skips remain wholly untoucht; for neither doth any thing else seem to remain which can be said, in truth none of these ought to be said: For if it be said in the first place, that there is so many points in the arch BD , as there are in the line BF , which cannot be said, since this is doubly greater than the arch: But if it be said secondly, that each point of the arch BD corresponds to two points of the line BF , it follows that the plane CE , is double the arch CH , when notwithstanding they are supposed equal; for when the points BC , are in the same radius AC , if the point C touch the point of the plane next following towards E , it will not be perpendicular to the plane CE . Surely AB when it touches the point of the plane BF in B , and is perpendicular to the plane, also AC which is supposed a right line will be perpendicular to the plane CE , which is parallel to the plane BF : Therefore it toucheth not the plane in any other point than in C , which if it should touch it would be also in the other next following point; therefore every point of the arch CH , touches two points of the plane CE , therefore the plane CE will be double the arch CH . Moreover it cannot be said that the altern points, or every other point of the plane BF , are toucht as it were by leaps, and not the other intermediate points, for at the same time in which some point of the plane CE is toucht answering the untoucht point of the plane BF , some point of the arch BD without doubt touches the plane BF , therefore it touches the point of the plane BF , which corresponds to the point toucht by the greater Wheel in the plane CE , for if it should not touch the Centre A , ought to be elevated above the line AG , and consequently the greater Wheel will not touch the plane CE , which is against the supposition; therefore no point of the plane BF remains untoucht.

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Moreover this difficulty hath great force against those authors who affirm that a body may be compounded of Mathematical points, whether finite or infinite, as may appear to the considerate, concerning which I shall say no more at this time.

Neither can it be salved by those who admit proportional parts to act infinitely; for while they say the point of Contact may be made in an undetermined part they speak unconceivably; for since the point of Contact is real and singular, I cannot see how it can be indeterminate, which if it be determinate, that is, in this place and not in another, than it becomes determinate in this part, and not in another; moreover 'tis something which touches distinct from all that which touches not; but to touch, and not to touch, are contradictions, and how can that be somewhat indeterminate from all that it touches not? Add, that there is no part in the plane B F, whether determinate, or indeterminate, which remains untoucht; how then does each part of the arch B D answer each part of the Plane B F, when there are as many more in that, as in this?

Some recur to the greater velocity whereby one Wheel is moved than the other, but if they speak concerning the motion of the Centre 'tis false, for there is one and the same Centre A to each; but if they speak of the motion of the orb they do not evade the difficulty by that, for the question is, why the arch B C although it be moved slower than the arch C H, nevertheless it is measured by an equal space, which successively touches the whole.

Father *Faber* recurs to the incommensurability of the plane, to wit, of a right line with the arch of a Circle, for he says, that although the right line C E be supposed equal to the arch C H, notwithstanding they can by no means agree, howsoever they are divided; but I ask whether they consist of an equal number of points, surely since they are equal, they must at least consist of an equal number of points, to wit, of Physical ones; or then all are toucht by the arch B D, or some remain untoucht, and so the difficulty returns: He says, the points of the plane B F are right, or streight, but the points of the arch B D are crooked; and although a right point be equal to a crooked point, and although one whole point is toucht by another point, yet notwithstanding they are not toucht alike, because the extension of the one is not analogous with the extension of the other, and he alleadges an example.

It may be objected against this explication in the first place freely, that each Physical point composing a Physical and real plane may be made; B F is a right line, but each point composing the periphery of the Wheel, or the arch B D, or

Fig. III. C H is crooked, for why cannot the same points of substance, or matter, which compose a superficial plane, compose a crooked plane? Moreover, when a rod of Iron, or a plate of metal is made crooked by bending, are there not the same points, if not more, in the crooked plane after bending, as was in it when it was a superficial plane? Secondly, also if we admit the points B F to be plane, and the points B D to be crooked, and so these touch not in an adequate proportion each point of the plane B F, nevertheless are there not little vacancies between one crooked point and another, which for that cause leave untoucht the points of the plane A, B, C, &c? Besides, that those crooked points touch not adequately, to wit, in all their virtual parts the plane points A B C, doth not cause that in each instant wherein the Wheel is moved by the motion of the orb, the new crooked point of the Wheel ought not to answer to the new point immediately next to that of the plane; if so be the point of the Wheel is equal to the point of the plane.

The same difficulties occur if the lesser Wheel be conceived to be so moved, that its Periphery be equal to the plane on which it insists; for then the greater Wheel will be so moved that its Periphery will be double of the other plane which it passes over; as if the Wheel A B D be turned upon the plane B I, and since the arch B D is equal to the plane B I, the point D will arrive in I, for then the point H of the greater Wheel at the the same time will arrive in L, when notwithstanding the arch C H is as great again as the plane C L; wherefore each point of the plane C L ought to answer to two points of the arch C H.

Besides in this motion, to wit, when the motion of the greater Wheel, is govern'd by the motion of the lesser Wheel, somethings happen yet more singular; for in the first place, some points of the greater Wheel go backward, as you may see after, that the Centre of the Wheel A is come to K, and the point D is come to I, the point H will be in L, and consequently go backward: In like manner the point of Contact C goes backward after that 'tis come to M, and consequently

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These things to explicate all that which is th not to confide (while the wh plane C L] as many and vario of many right place, from th motion, then motion, becau moved: From the motion of

all the points of the Quadrant CH go backwards, but the middle point R, chiefly goes backward most of all, for it goes down from R to S as appears, but the other points go backward here and there less and less successively.

Secondly, some points neither go forward nor backward, *viz.* in the end of the motion, when the point H comes to L, 'tis distant the same measure as before, from the same term, *viz.* from the line CN; So the point X will be in Z, and the point Y will be in V, and so in the end the motion gains nothing of space towards P; notwithstanding 'tis to be observed, that those two points sometimes go forward and sometimes backward, so the point X in the beginning goes forward but afterwards goes backward, but the point Y in the beginning goes backward, and afterwards goes forward, but because they go back the same space as they go forward, they acquire no space in the end of the foresaid motion.

Thirdly, all the other points of the arch Y Q N X go forward, that is, in the end of the motion they have acquired space towards P; so the point N will come to P, the point Q to O, the point T in *b*, &c. nevertheless all these points go not always forward, as appears from what's said in the 2. Prop. but because they go forward more than they go back, therefore in the end of the motion, it appears that they have gone forward; In like manner we will shew, that those points which are in the arch X R Y, and which go backward, do not continually, or always go backwards, but their going backwards appears in the end only, because they go back more than forwards.

These things being noted and observed, it will not be hard to explicate all those motions according to our doctrine; for to that which is the chief head of the difficulty, we say we ought not to consider that mixt motion, to wit, of the point H (while the whole arch CH, passes over only the space of the plane CL] as one only and simple motion, for it is really many and various, for as much as 'tis compounded Physically, of many right motions, to wit, 'tis compounded in the first place, from those right motions which compound Circular motion, then 'tis compounded of those and of another right motion, because the Centre A, common to each wheel is moved: From whence it comes to pass, that the point H, in the motion of the orb from H to C, while it goes backward

together also, while it goes forward, 'tis carried by the centre A, and as it were carried away by force towards P; notwithstanding it doth not go forward and backward, in the same Physical instant, as Father *Cabens* contends for in his book of *Meteors*, (for 'tis impossible for the same movent, to be moved by two opposite motions together) but so that some Instants it must go forward, and in others backward, which must needs be said of some points, as X and Y, as we have observed before, to wit, if the whole time, in which the point H is moved, from H going down to L, be supposed to be 12 particles, we say, 'tis moved; for example, 5 of those parts by a right motion from H, or from A in P, that is, by small parallel lines of A P towards P; and the other 7 particles to be moved in the opposite part in going backward, from whence it comes to pass, that when the regression is greater than the progression, in the end of the motion the regression only appears, to wit, when it comes in L, and because those particles of time wherein sometimes it goes forward and sometimes backward, in each short time are almost innumerable and insensible, because of the brevity, and makes the progression and regression by turns, any motion and time being assigned will appear only in the end of the progression if it be greater, or only in the regression if the progression be lesser.

Hence you see nothing hinders but that the points of the plane C L, are in number subduple of the points of the arch C H, when notwithstanding that arch passes over only that plane C L; for by the method explicated by us, doth two points of the arch very well successively touch one and the same point of the plane, to wit, if in the first instant the point C of the arch C H, while the arch D is carried by the centre A, touches the point of the plane C, which in the antecedent instant it touched not; and in the second instant, another point of the arch next to C, touches that same point of the plane C, while the motion of the orb goes backward, and, as I may say, creepeth upon that point C: Then again in the third instant, the third point of the arch touches the second point of the plane, and in the fourth instant, the fourth point of the arch creepeth upon that same second point, &c.

But it may be said that cannot be, because the centre A ought to ascend upon the line P A, I say, this is absur'd, if the motion

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motion and the circle be consider'd Mathematically, but not if it be considered Physically, for it ascends and descends always insensibly; and that by some small part of the plane only, and the compression and tension of the wheel, without which it cannot be Physically moved upon the plane, as will clearly appear from what follows.

Therefore all occasion of Error proceeds from this, that they would apply to Physical motion and Physical quantity, a motion Mathematically considered, or quantity and the nature of a circle, which is not given after a manner conceivable; moreover they consider the motion of the point H, by the crooked line from H in L, all one as if it were one only motion, when notwithstanding 'tis manifold and divers; like as they consider, for Example, the form of mixt, as it were one simple form distinct from the forms of those Elements compounding the mixt, when nevertheless 'tis not something absolutely distinct from them, but only in the manner as I shall shew in its place; wherefore also that mixt Motion may truly be considered as one simple motion by one only crooked line, because the rectitude of the small parts of which 'tis compounded is not sensible, like as the least particles of Elements are not sensible in mixt; but notwithstanding 'tis truly composed of the motion of the smallest right lines, since in nature there cannot be given a motion perfectly circular, as is shewn before.

P R O P O S. V.

A Globe, or Wheel, while 'tis moved upon a plane, whether Horizontal, or inclined, is moved by a mixt motion of a circular and a right, and is determined according to a circular motion from the impediment which is in the contact of the plane on which 'tis moved.

Fig. 112. **T**HAT 'tis moved with a mixt motion, appears from what hath been said; and that the circular motion about the centre arises from the impediment in the point of Contact; to wit, from some resistance and rubbing of the plane is proved, because the circular motion is not the natural by Prop. 4. Therefore it ought to arise from something without;

out; but circular motion as such, is caused from impediment only successively determining new *Impetus*'s by new tangent lines; but in our case when the centre is not impeded, but is also moved, it cannot be an impediment to the centre, nor to any thing that adheres to it, since nothing there is without it, therefore 'tis impeded from the plane only. Secondly, 'tis proved, because if any one push forward the Globe A by a push tending from C to D, in a line parallel to the plane B E, the Globe nevertheless is turned on the plain while it goes forward in E, but 'tis rolled in vain, unless it suffers some resistance in the contact B; for why is not the whole moved by a right motion, if so be its *impetus* is imprest by a right line, and parallel to the plane B E?

You will say 'tis easily moved, if it be moved by the mixt motion, from the right motion of the Centre and the circular of the orb, but why is it moved so easily? Moreover the Centre A, doth not more approach to the Centre of the Earth, by this that the Globe is moved circularly, for 'tis always distant to the Semidiameter A B, in the Horizontal plane B E: And the impulse when it is by the right line C D, is easier destroy'd if the Globe be moved by the motion of the Centre, together with the motion of the orb, than if it be moved only by the motion of the Centre; yea, 'tis easier destroyed if it be moved by both motions than by one only; but chiefly because the motion of the orb is not measured from that *Impetus* by a right line, but only by the motion of the Centre.

You will say, when it descends by an inclined plane, it descends easily, if it be moved together by the motion of the orb: For since in this case the Centre of gravity is without the line of direction towards the end of motion, 'tis determined from its Centre, or from its gravity to such motion.

I answer, neither in this case ought the motion of the Orb to move, if there be no resistance of the plane, for the reasons are muster'd up; for by this that 'tis moved with a circular motion, it comes not nearer the centre of the Earth, nor to the end of motion, for by how much the motion of the upper points are accelerated, by so much the motion of the lower points are retarded by that motion of the Orb, as appears by what is said; therefore such motion is in vain, when no impediment is taken away, for *Impetus* acts only to take away impediment, as is often said; therefore if there be no impediment

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diment in the point of contact, why doth the Globe always insisting in the same point on the plane, creep not on the plane? Doth not the *impetus*'s, whether they be violently imprest on the Horizontal plane, or by their natural gravity on an inclined plane, obtain their end in the same manner, yea, easier, as is said?

Surely if a Globe be stript of all gravity, and then receive some impulse from without by a right line, and should this Globe be in a vacant place, or in such a place wherein it suffers no resistance to motion, or no more in one part than in another, there would be no reason why it should move by the motion of the Orb, but it would be moved only by the motion of the centre, by a line determined from the imprest *Impetus*, whatsoever the same be, whether Horizontal, or inclined; or Perpendicular; for why should it rather move in one part than in another.

You will say from the foresaid Experiments, that while a Ball is thrown through the Air, 'tis moved with a double motion, to wit, of the Centre, and also of the Orb; and yet in the Air, there is no rubbing or scratching with the plane, nor no impediment; yea, it seems, if the resistance which is of Air, 'tis equal about the Ball, that therefore it should not move rather in one part of motion of the Orb than in another.

I answer, the Ball thrown is often so thrown, that at the same time wherein the *Impetus* is imprinted before 'tis separated from him that throws it, is not imprinted by one right line only, but many *Impetus*'s are imprinted successively by many lines, which compound some crooked line, for the Arm, or that which casts the Ball, while it casts it, is not moved by a right motion, but by a circular, that is, the Ball being separated from the Arm, while those *Impetus*'s are propogated in it, and new ones produced by the same lines, the Ball must necessarily be turn'd round about its centre. Hence it is that oft-times also a Ball is a little turn'd about its centre, if it be cast by one continued impulse by a right line, as you may observe: Besides that 'tis always but little turn'd, because 'tis never made so Spherical and perfect, but the Air resists more one part than another; add, that if it be not truly Homogenious, or all alike, so that the centre of the figure altogether agrees with the centre of gravity, since it can scarce be cast by that precise line which joins each centre, if it be not cast by this line, and even, so

so that the centre of gravity be right before, and presently is separated from the Thrower, or likewise if it be let drop freely, and falls from on high, it turns it self until the centre of gravity be placed in the formost part of the line of Direction, and so it contains the impetus of rotation which is likewise prosecuted towards that part: And this is the reason why things that are thrown, or cast through the air, are moved with a mixt motion of right from the Centre, and of mixt from the orb, and also of those that fall of their own accords; hence a Cylinder whose heavier part declines downward, while it falls of its own accord from on high, is not turned about the Centre, but sometimes about the axis, from the unequal resistance of the ambient air.

P R O P O S. VI.

In the descending of heavy bodies on an inclined plane, or through the free air, the motion of the orb, hinders not the motion of the Centre.

TIS proved, because the impediment which determines the Circular motion in the Globe, is not in its Centre, but in the Periphery, to wit, in the contact with the plane, or in the contact of the ambient air in that part to which the air most resists; and this impediment hinders indeed the motion of the whole Globe, and at the same time determines in it the Circular motion; but that circular motion hinders not, nor retards the motion of the Centre, which in like manner tends downwards, whether the Globe be moved circular or not.

Hence one impetus destroys not another, unless when the impediment of the motion of the Centre destroys the natural impetus, and the inclined plane, or the air while it hinders the motion of the Centre, and destroys its natural impetus, produces according to the laws of reflexion another impetus by the tangent, and when this impetus produces successively a new one by a new tangent, it makes the motion mixt, or really double, to wit, the motion of the Centre and of the orb.

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And you may observe in motion on an inclined plane, not only the motion of the centre to be accelerated, but also the motion of the orb, because when the motion of the orb is produced from the impetus, by the reflection from the direct impetus, if the direct impetus which moves the centre be greater, the reflected impetus is also greater.

Also you may observe in this motion all the parts to move with unequal motion, as may be gather'd from what has been said; from whence 'tis confirm'd again, that they are not moved by an intrinsic principle, for this would be alike efficacious, or powerful in every part and so would produce an equal effect in them all.

Hence you may gather the reason of the Experiments following, in which this mixt motion appears from the right and circular about the proper Centre, or Axis.

Experiment. I.

Play Boys make short darts with a point, in one end whereof there is a slit cut, and paper folded like a fourfold wing, and put into it, while this quavers, or shakes, the point goes before, and the paper so hinders the deflexion that 'tis the cause that while the dart tends rightly to the mark, 'tis turned together about the proper axis: The reason this, because the air while 'tis struck by those wings, resists the motion, which otherwise would carry the dart, by a right line, and it quavers to and again and hits on the sides of the Wings, and this certain reflection together with the dart, is converted into a circuit, since this motion is easy to the dart and hinders not the right motion; the same may be said of an arrow.

Experiment. II.

The like *Phænomena* you may observe in those flitting reeds, which Boys also play with, for they fix 3 or 4 feathers into wood, or a bony sheath, which while they strike the air, they force that wood or Cylinder to turn it self about its proper Axis; but if it be furnisht with only one feather, this circular motion will not be; likewise if any feather be broke, or not enough sever'd from the other, the circular motion ceases: But if the feathers are much sever'd from each other, the motion

is slower, *viz.* as well the right motion of the axis, as also the circular motion about the axis: And the feathers ought to be so fitted rising from the bottom to the top a little bent, and made crooked increasing the severing or parting: The reed or little Cylinder of wood always goes before in the motion, and the motion of the Axis ascends more swift, and the circular motion about the Axis less swift; moreover after the ascent 'tis turned downwards, and the Axis descends with a slower motion than before it ascended, but with a swifter motion about the Axis: And the reed, or little Cylinder, ought to be short and weighty, especially in the end that goes formost, and the feathers must not be too long.

Like to this, is that motion, which boys running make with a double stick, furnisht with a veil, and as it were a little mill turning about the centre, which is fixt to the moveable Staff, or Stick, for those veils, while they run in the air concieve a conversion and circular motion, which is joined with a right motion.

The reason of this *Experiment* appears thus, in the first place, that reed, or little Cylinder, furnisht with feathers goes before with a right motion, because 'tis heavier and endued with a greater impetus, and therefore leads the feathers whose motion the air resists more; and in resisting it comes to pass that they are reflected from themselves, and so turned about in a circuit together with the little Cylinder. From the air then reflecting, the impetus of the Feathers is imprinted successively by a new tangent, and from this impetus the feathers are turned about, and with the feathers the Cylinder, or reed, but the Cylinder, or reed turns not the feathers as a certain Author supposes, to wit, the right motion of the reed is not retarded immediately, but the right motion of the Feathers, which because they are light, have not sufficient Impetus to overcome the resistance of the air, but mediately and consequently the right motion of the reed is retarded, and determin'd to the motion about the Axis from the like motion of the feathers; hence if by chance the feathers fall off from the Cylinder in the way, the Cylinder or reed makes a certain longer space, because it hath not the impediment of the right motion from the feathers, but as yet 'tis turned about its proper axis for some little time by the circular Impetus preconcieved, which is not presently destroyed.

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Secondly, 'tis turned about the axis to that part, to which the feathers suffer the least resistance of air, for if the air should equally resist all, there is no reason why they should be turned rather in one part than another; hence they ought to be so fitted, that they may Strike the air unequally; which will be if they are seperated or divided unequally, and then the motion about the Axis will be Swifter.

Thirdly, one feather only will not do because it hinders the motion but little, neither is there in it an unequal resistance of the air, of which I spake; wherefore there are required two feathers at least, but three are better, because they less hinder the turning about the Axis.

Fourthly, if the feathers are not seperated, the reed is turned about the Axis little or nothing, because the air resists them but little; but if they are much seperated, 'tis moved slower by the right motion, or Axis, but swifter by the motion about the Axis; notwithstanding if they are too much seperated, the motion also about the Axis is slower, because too much resistance of air retards or hinders each motion; wherefore the feathers ought to be so fitted, that they do not impel the air with their whole superficies, but divide it by the edge as it were to cut it.

Fifthly, if the feathers are fitted in a right manner that they be neither too much seperated, nor too close, but a little bowed, with a moderate and unequal resistance of air which their edges divide; then the motion of the reed about the Axis is not only swifter, but also the reed is projected further, because the feathers are more easily broke off from the reed, and a little resistance of air with some inequality suffices to the motion of turning about the axis, since this motion is easy.

Sixthly, It ascends swifter while 'tis extended, than it descends afterwards, as appears clearly; from whence that is confirmed which we have shewn before, that heavy things naturally descending do not increase with the same kind of velocity, whereby the velocity of the same things cast or thrown, decreases while they ascend, and although both in the ascent and descent, the reed, or cylinder, goes before the motion of the Feather; hence while it ascends, because the *Impetus* in the beginning is greater of the Feathers, which are flexible while they suffer the resistance of the Air, they contract themselves, whence it comes to pass that they cut the Air the easier, and

therefore the reed ascends the swifter, but 'tis less swiftly turn'd about the Axis; but while it descends, because it acquires a lesser *Impetus*, the Feathers make a greater spreading that it may move oftner about the Axis.

Seventhly, If the Reed be lighter, it cannot contain so much *Impetus*, which easily overcomes the resistance of the Feathers; wherefore that it may hold out at length, so much *impetus* is required, that the Feathers cannot draw themselves, unless from a great resistance of Air they happen to be very much contracted, which while they are, it cannot be moved about the Axis.

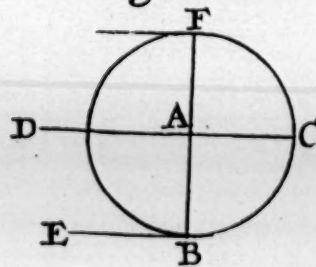
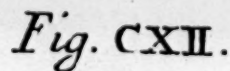
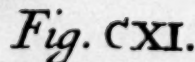
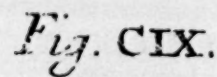
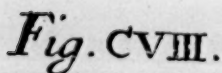
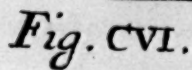
Eighthly, If it be longer, 'tis harder turn'd round the Axis, because it easily shakes to and again; but the Feathers cannot together hinder the shaking, and impress the circular *impetus* to the Reed shaking.

Ninthly, If the Feathers are longer than needful, they hinder the right motion, or if they are likewise too broad, or too much separated, or if they are too short, and much contracted, they are not determin'd to motion about the Axis, for the reasons assigned; wherefore care must be taken, as well to the length as the breadth, and separation respectively to each other between themselves, and to the gravity, or levity, length, or shortness of the Reed, or Cylinder.

Tenthly and *Lastly*, the motion of the bearing, and about the Axis is mixt of a triple motion, one whereof is from the violent *Impetus* while it ascends, another from the gravity, and the third from *impetus* by reflected motion, successively by divers tangents whereby the circular motion is effected; and from all these motions, results the spiral motion as is manifest, and a spire is conceived about a crooked Cylinder, which possesses the whole place of air, or the way which the Reed successively Occupies.

Hence 'tis easy from what has been said, to determine the lines which are described by each point of the Reed, and also of the Feathers; in which also some trembling motion always intervenes.

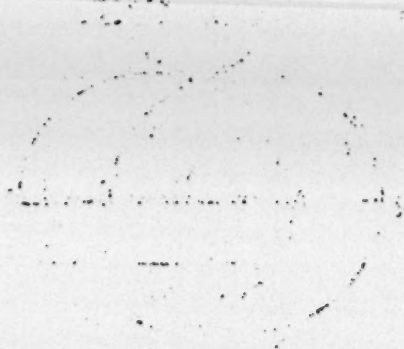
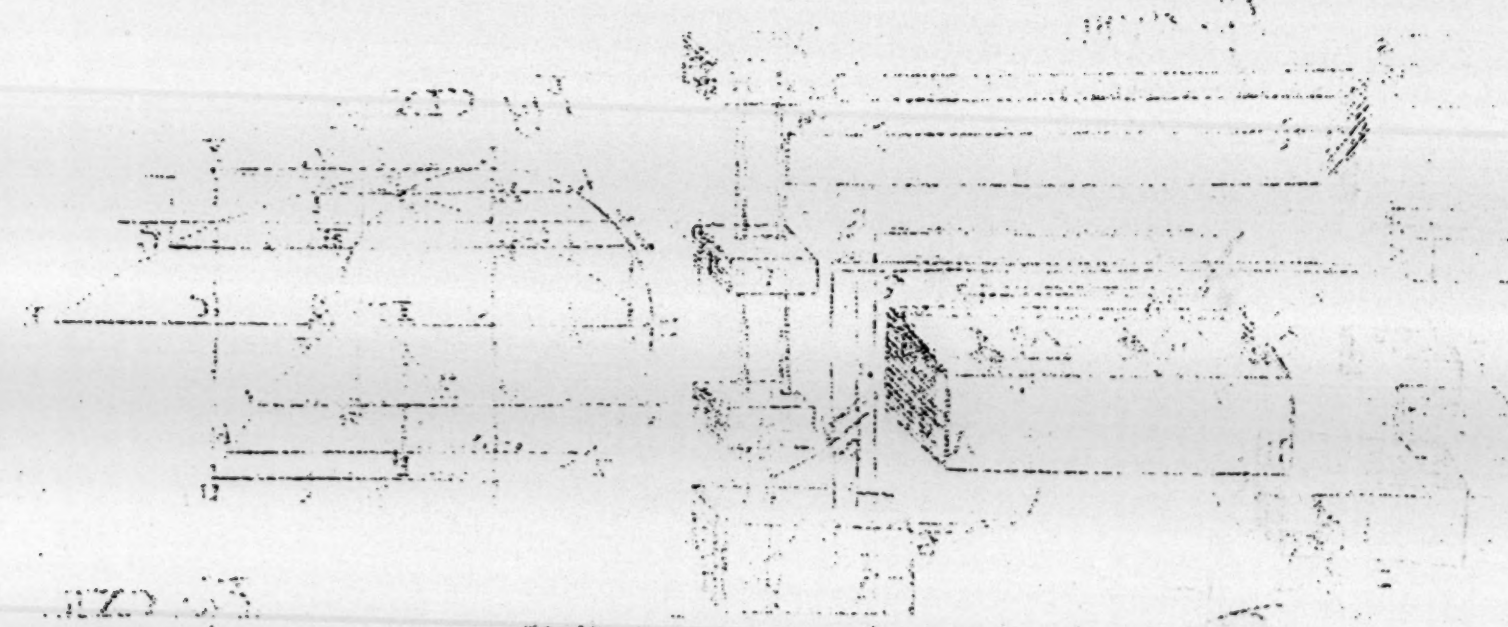
Also a reason appears of the motion of the double staff covered with the veil, which is turn'd about circularly, while in the interim 'tis conveyed by a right motion Horizontally by boys, as they run; also that motion is manifest to be spiral, which hath Spires more thick and close, in which 'tis moved
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Book VIII.
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P R O P O S. VII.

A reason may be given why a little Wheel, or little Globe, being prest against a Table, is first thrust forwards, but afterwards turns it self back again upon the Table.

THE reason is, because while 'tis strongly prest again the Table under it, this resists that in the point of contact, and while at once the *Impetus* is imprest forward by the retraction of the Finger, new contacts are made in other points often times, that therefore it conceives a circular motion contrary to that whereby 'tis moved, if the *Impetus* be only imprest forwards Horizontally; hence 'tis, that while it runs forward, at the same time 'tis moved circularly about the Centre, by the motion of rotation back again, *viz.* towards the Finger; and because that circular *impetus* continues longer than a right one, this ceasing, the other continues and compleats its effect, and so the Globe turns back again; for it cannot be turn'd about its centre, while it rests upon the Table, unless at once it be moved with a right motion of the centre towards the same part by the resistance of the Table in the point of contact, where you see this motion truly to proceed from some reflection, for the *impetus* imprest backward after that, is so weak (for 'tis weakened from the resistance of the plane Table) that it cannot overcome the resistance which is in the point of contact, from the Tables resisting 'tis somewhat reflected, and when the circular *impetus* continues, whose effect is easily obtained, neither can it be obtain'd but that it must role back again, therefore 'tis no wonder that it retroceeds.

Therefore 'tis false, that any *impetus* can persevere without the motion which exacts it, as Father *Cabens* would have it; for a little Globe, or little Wheel, is always moved with a circular motion about its centre towards the extrudent, in the same time wherein the motion of the centre tends forwards; yea, I have observed diligently, that if sometimes one touch a Globe while it runs forwards, it will not role about its pro-
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Per centre, but creep upon the Table, which it always toucheth in the same point, then the Globe reflects not, nor goes back.

And 'tis to be observed, that while the Globe tends forwards, the motion about the centre is weak and slow, to wit, because the right motion upon the Table in a manner resists the contact, for it drives out the motion about the centre into the opposite part, to wit, forward; but the *impetus* ceasing, whereby 'twas moved forward, the impediment of the motion about the centre ceases, yea, it acquires a new determination to this motion, to wit, from the reflection of the planes resistance.

This reason assigned by us, appears not only from this, that, as I said, the Globe is not rolled back again, unless it be rolled about the centre also, in the same time which it runs forward; but also from this following experiment.

Experiment III.

Fig. 113. Grasp the Globe A, so with your Fingers about the Pole A, and the other opposite to it, that you may imprint the circular *impetus* about those Poles, or about the Axis whereby 'tis moved from E through H to G; and at the same time, cast the Globe through the Air, so that it goes by the line E F C, and falls upon the Horizontal plane in B, if that motion about the Axis be swift enough, either it will stay in the point of contact B, and yet it will be turn'd about for sometime upon the Axis from C through D in B, or also many times 'tis reverted from B towards G upon the plane; where it appears, in so much as the Globe is determin'd to the motion of rolling back again upon the Table, or Pavement, after that 'tis cast or thrown forward through the Air, in so much

Fig. 114. also it hath the motion about the Centre, while it is borne through the Air; for from this it is that the *impetus* being destroyed, by which it tends forward, while the Globe falls on the pavement, 'tis necessarily from thence reflected back again. For the Globe projected in the Air, proceeds by the line A B C D, and in the mean while is turned from B towards C D about the Centre C, while it touches the Pavement E D in D, according to the laws of reflexion it ought to reflect in F, and preceeding further to the same part with

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with so much impetus as DI; but if that impetus be smal (even as 'tis when the line CD comes near to the perpendicular CL) and the impetus whereby 'tis moved about the Centre be pretty strong, this prevails over that, and while it perseveres the Globe must needs role towards E upon the Pavement; hence it does not always go back, but only then when the motion about the Centre is swift, and it falls upon the pavement by a line which approaches more to a perpendicular.

P R O P O S. VIII.

The motion of a Rope, or of a Ball, or Globe, fastned to the end of a Rope about a Cylinder, is a Spiral motion compounded of many Circular.

Spiral motion is divided into many kinds, one whereof is when the motion is made about the same Cylinder, so that the circles are always equal, and this is mixt of circular only and right: Such as we said was the motion of the reed, or Cylinder, furnisht with feathers; and of the double staff provided with a veil, &c. and there is another Spiral motion also, which is made about the same firm centre, but by circles or wreaths enlarged or lessened successively more and more, or departing from, or approaching to the same centre; moreover there is another Spiral motion, in which the wreaths are not only enlarged or lessened successively, but they likewise retire from the former centre, to wit, it always changes the centre, and this is mixt of many circular, and of the right motion of the centre; but the second kind of Spiral motion is mixt of lesser circles only successively; the first *Fig. 115.* spiral motion is shewn by the figure AB, the second by the figure CD, the third by the figure EF.

These things being fore-known, if we consider the motion of a rope about a Cylinder, whether the rope be turn'd about by the Cylinder by circles, having divers centres in divers points of the Axis of the Cylinder, if it be, 'tis a spiral motion of the first kind; but if the motion of any determinate point in the rope be consider'd, as for example, the end of the Rope

or.

or the Globe annex to the end of it, then either it may so be turned about by the Cylinder, that the same centre always remains in the same point of the Axis, and then it appears, that since the radius is shortned successively, from that Globe is made a spiral motion of the second kind, which is compounded of circular motion only, for there may be perceived so many circular motions, although not perfect, as there are wreaths, or rather so many new determinations to new circular motion, as there are conceived *Radius's* one successively shorter than another; or, it may be so turn'd about by the Cylinder, that the centre is changed at once, and then the motion of the Globe, or the end of the Rope, will be a spiral motion of the third kind, such as may be conceived to be made about the Cone E F, from F in E, which appears to be mixt from a right motion of the centre, through the Axis of the Cone, or Cylinder, and of many circular ones intelligible by Sense; for it cannot truly be said, that there are many circular motions, since none makes a perfect circle, yea, no part of that spiral line is part of a circular line, but if it be taken as a small part, 'tis a right line from what hath been said before; if as a compounded part, it consists of many right lines, *viz.* of many Tangents, yet not of the same circle, but of divers circles as appears.

Hence 'tis, that if a Cylinder be thicker, and a Rope of the same length being put on it, 'tis easier and with less imprinted *impetus* turn'd about by the Cylinder; to wit, because the parts of the circumference of the Cylinder are those which resist by impulse by a right line imprest in the beginning, and by the impediment, or a certain reflection, they determine to new and new lines oftentimes; and by how much greater the circumference is, by so much the less frequent is that new determination, as appears from what has been said, and so the lesser *impetus* is destroyed, as that which is moved by a greater circle is less wearied or tyred.

Secondly, It appears why a Globe doth not ascend, nor is turn'd about by a Cylinder, if the *impetus* be too weak in proportion to the thickness of the Cylinder, or to the length of the Rope; for although it be so great that a right line could ascend to that height, yet while it often suffers resistance by reflections and new determinations, 'tis much abated.

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Thirdly, if it be once turn'd about, it effects all the rest of the turnings about easily, because the circles are successively lessened, and so the motion is always lesser, when notwithstanding the former impetus perseveres almost the whole time: For if once the imprinted impetus decreases less than the wreaths decrease, one of the greater wreaths being finisht, the other lesser are also easily and therefore swifter accomplisht, and the velocity is increased proportionally to the lessening of the wreaths, not absolutely but comparatively to the remaining impetus, since also here, as is said, 'tis decreased or lessened successively, notwithstanding less than the wreaths; for if the wreaths and the impetus were lessened equally, the motion would not be quickened.

P R O P O S. IX. *Fig. 116.*

If a Globe, or Wheel, be moved and turned about on a crooked superficies which is immoveable, it makes a mixt motion from a double circular.

L Et the crooked superficies be A B C, upon which the Globe B D is turned towards C; while the point E comes to F, the Centre of the Globe H comes to G. For the Centre alone is moved only by a circular motion through the arch H G I; but all the other points of the Globe are moved circularly by the motion of the Centre, and in like manner also by a circular motion about the proper centre, or axis.

But 'tis to be observed, that this mixt motion may be consider'd divers ways, for the crooked superficies on which the Globe is roled is either convex, or concave; and again, the Globe is turned either on a greater circle, or a lesser, or an equal; if notwithstanding the Concave be equal or lesser, the Globe, or Wheel, cannot be moved, as appears.

Moreover, observe that the Globe B D, whether it be less, or equal, or greater, than the Wheel, or crooked Superficies, on which 'tis moved, may be so moved that the Line of the moveable Globe B E, which successively touches the Circle A B C is equal to the Line B F, when the point E comes to F; or it may so be moved that the line B E is lesser, or lastly, so that it be greater than B F.

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Thirdly, the foresaid Globe may be understood to move by the motion of the Centre towards C, and in like manner by the motion of the orb towards A, to wit, so that the point B tends to E and D, &c. and in each case the motion of the Centre may be equal to the motion of the orb, or greater, or lesser.

Fourthly, Note, that if *Copernicus* his opinion be true, that the earth is moved with this mixt motion, to wit, by the motion of Centre through a circle of the greater orb about the Sun, and by the motion of the orb about the proper Centre; and the motion of the Centre should be greater than the motion of the orb, according to the common opinion concerning the Diameter of the great orb, which the earth runs through in one whole year: Where also observe, that every point of the same parallel Circle are moved with unequal velocity; for whether we suppose the motion of the orb and the motion of the Centre to be towards the same part, suppose towards C, when the point E comes to F, and the Centre H in G, the point B will be in E, and the point D will be in L, wherefore the point of Contact B is moved slowest of all, but the opposite point D swiftest of all; that answers to the Nocturnal meridian, this to the Diurnal meridian. Or whether we suppose the earth to be moved by the motion of the Centre towards C, and the motion of the orb from B in E, D, &c. in this case the contrary happens, to wit, the point of Contact B is moved swiftest of all, for it comes to L, and the point D slowest, for it comes to E; and these kinds of motion of divers points of the same circle will be slower, or swifter, according to the divers proportions of velocity of the motion of the Centre, and the motion of the orb, nevertheless all will be by crooked lines, as appears by what has been said.

Fifthly, after this last manner, some Epicycles are said to move by Astronomers, to wit, by the motion of the Centre to the East, according to the Series of the Signs, or, as they say, in the Consequent; suppose the Centre C towards A, and the Supream point, or the Planets *Apogæum* D, moved in the opposite part from D in E towards the west, and, as they say, in the Antecedent.

But since the foresaid motion may be divers according to the divers magnitudes, and proportions of the Circles, it appears nevertheless from the doctrine deliver'd before, that the lines

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lines of all the points described by the motion of any circle, may be determin'd howso'ever 'tis moved on one or another, which may be of great use in Astronomy.

P R O P O S. X.

The Spiral motion of Sphæres may be explicated, to wit, when a Sphære is moved by a motion mixt of Right and Circular, or of two Circular ones.

Fig. 117. **F**OR in the first place, let the Sphære BC be moved by its centre A through the right line AH, and at the same time turn it about the axis BC; moreover every point, except the Poles B, C, describes Spiral lines, as if they were Spires, or wreaths, about divers Cylinders, about the greater Cylinder, truly the spire which it describes is from the point F or G, but about the lesser, which is described from the point, next to the Pole C or B. But if it be turned about the Axis FG, or any other oblique, it will be another divers mixt motion in divers points, whose lines may easily be found by the foresaid doctrine.

In the second place, let the point G be moved through the arch GC, and at the same time understand it to move about the Axis BC, it will be a Sphærical Spiral motion mixt of a double circular.

Thirdly, let the same point G be moved through the right line GC, while 'tis moved also about the Axis BC; the motion will be conicaly Spiral, mixt of Right and Circular.

Besides the *Sphæric Spiral motion*, there may be made another motion *Conoid Spiral*, to wit, if a *Conoid* be turn'd about one, or about the other Axis, while its point is somewhat moved through a right line; and 'tis of a threefold kind, viz. either *Elliptic*, or *Parabolic*, or *Hyberbolic*, as appears by *Geometry*, and from the *Mechanick* description of those figures.

P R O P O S. XI.

In the motion of a globe upon a plane, a three-fold motion may conjoined, so that it may be mixt of a Right and two Circular ones.

THis experiment appears from the game at Billiards in players balls, for while the Centre is moved through a right line, and the other points about the Centre, suppose in a vertical circle, if the globe either by oblique reflexion, or by a new impulse, be never so little turn'd aside about the Horizontal, or other line, it conceives another circular motion also by that line, and so besides the right motion of the Centre there is a double circular. And from this appears the reason of the said plays; as for example, while the ball is moved by the right motion of the Centre, and by the circular motion of the orb together, if the Chord be toucht lightly 'tis turned a little aside and makes another circular motion, from whence it follows afterwards, that the leap decieves the player, because the new circular motion acquires a new determination in the reflection, &c.

P R O P O S. XII.

A Globe, or such like body, insisting on a plane cannot move circularly about the Penpendicular Axis, unless at the same time it be imprinted by a double impetus in opposite parts. Fig. 118.

LEt the Globe, or Top, such as children play with of a Conoid figure be A B, resting on a plane in the point B, and you would have it move about the axis A B in an Horizontal circle C D : I say, it cannot so move, unless all under one it be imprest; or forced by a double opposite impetus, one, for example, in C towards the right hand, and the other in D towards the left hand part; the reason is, because if it be forced by one
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impetus only it will be determined to one only right line, and since there is no impediment supposed, which may hinder the Globe that it should not be moved by that line, it will be moved by it, and so be turned on the plane in the vertical circle $A C D B$, but the top will fall to that part towards which the impetus is imprest. But if at the same time another impetus be imprest on the opposite part, when these two impetus's are not by the same line, but by two divers lines parallel to each other, either may have its effect by chance, and when one at once hath the reason of the impediment with respect to the other, least the Globe, or top, prosecute the motion by right lines, 'tis determined to circular motion, for neither can those two impetus's obtain their effects any other way; hence it is, that the top being taken by the head, or its end of the Axis A , and being cast off by the fingers in contrary parts we make it Spin, or turn in circuits; and it perseveres this circular motion a long time, because the impetus is not destroyed by the weight since the top is in *Equilibrio*, but the only by rubbing with the plane, and from some resistance which every moment changes the determination of the tangent lines; hence the smoother the plane is, and the sharper the point of the top is, the longer time it spins, or prosecutes the motion.

But when we wind a string about the top, and retain the other end of it in the hand, and casting it from us it spins, then in like manner that double impetus happens in the opposite parts; for not only while the string $D E$ unfolds, doth it draw towards us the point D , but at the same time with the same string we throw the top from us like a sling; and the motion of the top endures longer being cast in this manner, by so much as the impetus's are greater and the string the longer, because a power applied remains longer, and while the projected impetus perseveres the other impetus of the string being retracted in the opposite part, and hindering the former impetus, gives many new determinations to new and new tangents.

While the top is cast, it makes a motion mixt from the right motion of the centre, and of the Horizontal circular, as appears, or also of another right motion which tends downwards.

Secondly, when it insists on a plane, if the same point on which it insists be moved only by a circular motion about the axis, then 'tis said to sleep, yet in truth the motion of the Axis is
but.

but little moved about the Centre of gravity which is in the Axis ; but because it either finds it on the plane, or makes hollow some little trench of it self, this trench detains the Axis, least it should go out of it, unless afterwards the Axis begins to incline more.

Thirdly, thereupon it moves always by a motion mixt of a circular about the Axis, and of a circular of the ends of the Axis, so that also if any point of the Axis remain immoveable, yet the extreame points of the Axis describe two circles, one in the plane, the other in the air above.

Fourthly, sometimes another motion of the whole Axis happens to the foresaid motions, which is carried about not in a perfect orb, but spirally, the Spires, or wreaths, successively more and more contracting untill it begins to sleep ; and this motion is always on that part to which the outer portion of the top by its motion is turned about the Axis ; to wit, because this Spiral motion of the Axis is determined from the circular motion about the Axis ; you see therefore many motions in a top, one about its Axis in an Horizontal circle, another of the same Axis, and the Spiral of the Centre ; lastly, another of the turning round of its Axis about some of its points, by which motion of turning or trembling the foresaid little circles are described by the top and point of the Axis.

But the Impetus of the orb about the Axis ceasing after that, and the turning about and the inclination of the Axis prevailing, the Centre of gravity so departs from the line of direction, that the Impetus of the orb cannot keep the Axis erect, the top falls ; and then because in it there remains as yet much of the former impetus, it makes still some oblique turnings or Circuits, which although they seem to be made in the opposite part, yet they are made (if you attend rightly) on the same part on which the circular motion about the Axis was made ; which when 'tis hindred by the contact of the Plane, therefore afterwards 'tis rolled about upon the Plane, and now is more moved by the motion of the Centre which before was hindred by motion of the orb, or that from this you may know the nature to be loved of the right motion of the Centre, but not of the orb about the Centre.

Mechanick Powers.

Of Circular Motion artificially fitted to Mechanick use.

BOOK. IX.

YOU shall scarce see any ingenious Engin in which either circular motion doth not appear, or at least that which may not be reduced thereto, notwithstanding in this place we shall treat only of those kinds of Engines, or Inventions, which immediately depend on the Principles, and Doctrine of Circular motion hinted at before.

Problem. I.

To make divers kinds of Wheels commonly used in Engines.

Generally we make use of two sorts of Wheels, one whereof is furnisht with teeth, and the other hath none; those that have none are single Wheels, and Pulleys, which are hollowed in the Periphery for the Rope to move in, as also Wheels with handles to turn them by: And the first sort of Wheels contains as many kinds, as there are various forms of teeth, which I think fit to describe in the first place, for the better understanding of what follows, and that any one may know how to make choice of those kind of Wheels which he esteems most fit for his occasion.

Teeth, or, as some call them, *Claws*, or handles turning round, their chief use about Wheels is, that they lay hold on, or bite each other, and being folded in each other they cause a reciprocal.

procal motion, and they are various as you may see in *Fig. 119.* from whence the names of those wheels are divers.

A toothed Wheel is, that whose Periphery sticks out with little handles endued with *Semicylindric* form, as in the arch A F, or a plain sided Prisme, as in the arch E F.

A Fingered Wheel is, that whose Periphery is garnisht with plain Cylindrick small stakes, as in the arch A B, or somewhat like Cylinders, as in the arch B C.

A sharp pointed Wheel is, that whose Periphery is cut in with little handles turning round like the figure of a point of a Sword, or of a tongue, as in the arch E D may be seen.

A Studded Wheel is, that in whose Periphery little Sphæres, or Convex Hemisphæres are disposed, or the Concaves are made hollow answering to the Convexes in the other Wheel, the first parcel refers to the arch C D.

A Starred Wheel, is that whose Circumference is furnisht with three sided Prismes having each side equal, as in the arch G H.

A Snagged, or sawed Wheel, is the same as the former, only with this difference in the former, the triangular sides of the Prisme are equal, but in this they are unequal, as in the arch G N.

A helical, or screw Wheel is, that in whose circumference channellings or grooves are made, according to the quantity of the angle of the Axis of the inclined wheel, whatsoever figure the same hath, which nevertheless are reduced to four kinds, *Semicylindric*, as in the arch A F, *Trigonal*, as in the arch G H, of four sides, as in the arch K L, *Trapezias*, or unequal 4 sides, as M L.

A hooked, or crooked Wheel, is that which hath hooks disposed in its circumference, as in the arches H K, and N M, you may behold.

Also Wheels are named with respect to the figure of their Wheels, let the teeth be what they will; for some are called plain Wheels, or *Orbiculates*, in which the bases of the Cogs or Teeth are all in the same plane; others are called *Convex Cylindric*, when the Cogs are disposed in the outer superficies of the Cylinder, or any circle thereof: Others are called *Concave Cylindric*, in whose inner Cylindric superficies the same Cogs are disposed: In like manner some Wheels are called *Convex Conic*, others *Concave Conic*, even as is said of Cylindric: Lastly, a Wheel

Book IX.

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to apply Weights
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a Wheel without teeth, and whose Periphery hath nothing sticking out, they call smooth or even.

Note, that all the kinds of teeth, or Cogs described, or any other such like, may be made, not only in the Periphery, or outermost superficie of the Wheel, but also in one or both of the lateral superficieses, or Circular, or Cylindric bases.

Problem. II.

To apply Weights, or Powers (moving by their natural gravity) to Clocks, or other Engins.

Almost all kind of Engins, which are moved by inanimate Power, are usually made with some Wheel, or Cylinder, to which a weight being hung, while it endeavours downwards by its natural gravity, it moves that Wheel, or Cylinder, and that puts the other parts of the Engin in motion, as appears in common Wheel Clocks: And weights may be applied to Wheels many ways, which we will unfold, before we proceed to the making of the Engins: The first way of hanging weights to common Clocks, or other Wheels, which by some determinate time, being placed in the middle and impelling, ought to turn them round, is, that one end of the Chord, or Rope, be fixt to the Cylindric Axis of the Wheel, and the other end sufficiently fastned to the weight, as you may percieve in the Figure: And in this practise you *Fig. 120.* must beware, that the Cylinder be not wanting to the rope, for it ought to have only so much length, that the whole Chord may be turned about it, for if the rope be twice wound about the same Cylinder, that is, if the latter windings of the Rope fall upon the former, it will come to pass that the foremost motion (*viz.* while that part of the Rope descends which is wound about the other) the motion will be swifter than that of the latter, to wit, while the remaining part of the Rope descends which is immediately wound about the Cylinder.

The second way is, when weights are hung to each end of the Rope, as appears in the Figure: For the Rope ABC is put upon the Pully D, in whose Periphery there is a hollowing, or groove cut arching so that the Rope may lie in it, and recieve firmly in it the draw-

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ing force of the weight; and the weight A must not descend without turning the Pulley about, and consequently raises the weight C.

In practicing this Artificers are commonly mistaken, for some in the foresaid hollowing of the Pulley D, make 6 or 8 sharp points sticking out to hinder, least the Rope being drawn by the force of the weight A should not turn about the Pulley.

But those sharp points render the motion of the Pulley, and so of the Clock, or other engin, altogether unequal; others make the Cavity or hollowing of the Pulley narrower in one place, and wider in another, from whence it follows, that the Rope being unequally distant from the Centre makes the motion unequal.

Therefore if the Rope slips without turning the Pulley those sharp points may be used, but a greater number must be affixt, and they ought to stand out all alike, and equal upon the Periphery of the little Wheel; which may be performed more safely if you glew on some little balls like button moulds or beads to the whole Chord, or fix them in some other manner which may be all alike and equally distant to each other; and in the Cavity, or hollowing of the Periphery of the Pulley, make little holes or cavities right with the same distances, which Cavities must answer the little buttons or beads, and receive them within them one after another: Some instead of these, rye knots in the rope, being equally distant.

Fig. 122. The third manner in use is, when the space for the descent of the weight is too low, or short, or of too few hours; or if it be sufficient, we would notwithstanding extend the motion of the clock, or dial, to more hours. For then we double the Rope, which may again be done in a twofold manner; first, one end of the Rope is fast bound to some place A, and the other end to the Axis, or Cylinder E, of the Wheel, which it ought to go about; as for example in D, this Rope ABD sustains the little Pulley C with the weight annex to it, and this whole weight together with the little Pulley C ought to be double of that which is hanged to the single Rope; also the Rope may be triplicated, quadruplicated, &c.

Fig. 123. if there be added above and beneath other Pulleys, in which case also the weight may be in like manner triplicated or quadruplicated, &c. In the second place by the

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the double Pulley D, C, one of which being annex to the weight C, and the other to the Counterpoise D, and the ends of the Rope B and E are fastned to some firm immovable place; so while the weight descends with the Pulley C, it turns the Wheel, or Pulley A, and lifts up the counterpoise D.

Fig. 124. The fourth manner is by a continual Rope, disposed in such manner as the figure shews, in which A is the lowest Wheel of the Clock, or such like Engin, or the pulley annex to the Wheel, and made hollow in the Periphery to receive the Rope firmly, as we have said before. B is another Pulley like to the former, and moreover furnisht with saw-like teeth, and with a pin C so fastned to the side that it endeavours against the teeth while the weight D descends, that the Pulley B be not turned about at that time; but the Pulley A is roled about and lifts up leisurely the counterpoise or weight E annex to the pulley; where you see there is no extream head of the Rope, but it is one continued Rope, and put into the Pulleys, whence 'tis called perpetual or infinite. When therefore the weight D descends to the lower part, and the weight E is carried to the upper part, the Rope being taken by the hand in F, and by drawing downwards raises the weight D again and depresses the weight E, for the pin C endeavours not against the motion of the Pulley B, but alone against the opposite motion.

The peculiar conveniency of this Rope, and the application or disposition of the weight consists in this, that in the same space of time, wherein the Rope is drawn, and the

Fig. 125. weight raised to continue the motion of the Clock, the motion of the clock is not interrupted, as happens in others; for also while 'tis drawn upwards by drawing of the Chord in F, it discharges its office in enforcing the Pulley A, which truly is of great moment to the exact perfection of Clocks, and such like Engins, and the knowledge of time.

Likewise you see by this doubling of the Rope, that the slowness of the weight's descent is doubled to that it would have by a single Rope; and it might, if need were, be quadruplicated, and be made greater than any given proportion. You may add to the two pulleys A, B, another Pulley G, and to the Pulley D adjoin another little Wheel about the same Axis, or if divers, join it at least with the other Axis. Then this perpe-

tual Rope being drawn about all the Pulleys, *viz.* ADGDBEA; for so the descent of the weight D will be four fold slower, and therefore the weight ought to be four fold greater, yea, and somewhat more, because of the much rubbing of the Pulleys with the Rope, and the resistance, &c.

Fig. 126. The fifth manner is this, the Pulley B is understood to be firmly affixed to the lower Wheel of the Clock, the other A stablished somewhere commodiously, and being furnisht with saw-like teeth with an Iron Pin to endeavour against the weight, as is said before; from the perpetual chords of these Pulleys hangs the weight H in the little concentric Pulleys EFG and CDN, one of which is conjoynd immovably to the other, and both together about the common axis of that which turns easily: Moreover below let there be two Pulleys K and L conjoined in their centers to the common beam KL, in the middle whereof hang the weight M. About these and the former Pulleys draw two perpetual chords by this artifice, the first Chord is BLGFEB, to wit, so that it fold about the Periphery, or circuit of the whole Pulley EFG once: The other Chord in like manner, must be drawn about the whole Periphery, of the lesser Pulley CDN, concentric with the former, so that this whole Chord be ACNDCKA. But now that which is said concerning this last Chord, and the pulleys belonging to it, is, that it ought to be done altogether like to the other, but placed on the other face or side of the Pulleys, which in like manner contains a certain lesser Pulley equal to CDN, standing out on the other part and divides the whole office of holding or bearing up with the other; wherefore it behoves the Pulleys A and K to be alike.

That therefore the weight H be drawn with its Pulleys on which it hangs, you must apprehend the Chord AK, either alone or compared with another, *viz.* in E, and drawn downwards; for so it comes to pass that the weight H ascends, yet in the mean while the motion of the Pulley B is not stopt, and consequently neither the motion of the Clock, or other Engin: So likewise it appears in this method, as also in the precedent, that the attraction of the weight may be continued as long as you please without hindering the motion of the Engin. Lastly, it appears in this last method that the motion downward of the weight may be made slow according to any given proportion,

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tion, to wit, in that proportion which the diameters of the Concentric pulleys CDN and GEF have to each other; and in the same proportion the weight will always be increast.

Problem. III.

To apply a Sphærical, or rolling weight, to the Wheels of Clocks, or other Engins, by finite Chords, as well as by infinite Chords,

Since oftentimes it is necessary in the artificial construction of Clocks, and other Engins, to make use of Sphærical or rolling weights, two or more whereof succeed each other mutually to continue or perpetuate the motion of the Engin, as will appear by what shall be said; therefore we will deliver a double method, whereby it may easily be obtain'd.

Fig. 127. First, it may be done by a perpetual Chord, or Thong of Leather twisted; for let there be two Pulleys, or short Cylinders A and B, A being fixt to the lowest Wheel of the Clock, and B stablisht in the lowest place to which the weight ought to descend; put on each the perpetual chord ABCDA, or a Thong made of the Hide of a Beast; then take another Thong altogether like to the former and put about the same Cylinders, or on two other pulleys parallel to the former and distant from them so much as is the diameter of the Sphærical weight D, which is sufficient to turn the clock or Engin, this interval of the double Thong being observed, joyn one Thong with the other by ranks of certain transverse Irons semicylindrical, whose bases are EHI, LMN: And they are easily connected if you drive a Nail through each Semicylinder, and the Thong which folds about it, or if by chance the Thongs of the Semicylinders strain in the middle, it will make a Scale, as appears in the Figure PQ, so that the Sphæric weight D being placed between the foresaid degrees will be sustain'd by the lower pair of Cylinders, viz. in F. But that these kind of perpetual Scales may be turn'd about with the Cylinders A and B with an uniform motion, there must be made hollow Semicylindric grooves or Channelings in the Peripheries of the Cylinders, in which are received the convex Semicylinder of the Scale.

If the Sphæric weight D be of a great bulk, the Thongs may be made of double or triple Leather that they break not, or instead of them Iron chains may be used.

The

The chief use of this perpetual Scale is to continue the motion of the Clock, or other Engin; for after that the weight D is descended to the lowest part G, 'tis cast away by the Scale, which will be done either from the Pulley B, or better from some obstacle fitted below for this purpose; then the Globe breaking out from the Scale in the lower groove G, lifting up some pestle of Iron by means of a Thred or Chord, opens an entrance to the other Globe in the upper groove E, that it may succeed in his place on the top of the Scale; but the former Globe deposed in G is lifted up again to the groove E, by an artifice which we will shew in the following Problem, that it may again descend by the Scale, &c.

Fig. 128. Secondly, it may be done thus, affix the Pulley H to the lowest Wheel of the Engin, which ought to move and turn easily about its Axis, having in its Periphery Saw-like Teeth with the Pestle R, which being fixt in some place of the Wheel, and fitted with a plate of metal pressing; put the Rope LHK upon this Pulley, fastning to one of its ends L some little Box or Basket wherein the Globe may be received, and to the other end K, hang a weight of such gravity, that it may draw up the Basket free from the Globe, from the bottom Q to the top, where now it appears in the figure, which the Pestle R will not hinder, which hinders only the opposite motion of the Pulley H, and that the Globe may be contain'd within the Box or Basket, and not slip out of it, erect two or more rules P Q and M N, &c. But after that the Box with the Globe is descended to the bottom Q S, the Globe must run out of the Box, either by mangling the rule N, or by the declivity of the bottom Q S; Lastly, the Box or Basket being freed from the Globe, is lifted or raised upwards by the weight K, and being advanced to P M, takes in there the other Globe equal to the former, and that the Clock, or other engin, may be kept in motion while it is let down in Q, and raised again in M, we will shew by and by.

Problem

Book IX.

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Problem. IV.

To convey weights, moving an Engin up to the upper part, after their descent to the lowest part.

Fig. 127. **T**His may be done many ways; first, by the perpetual Scale described in the preceeding Problem, for if you understand a Toothed Wheel joyned to the Pulley A, and firmly adhearing to the same Axis, if then this toothed Wheel be moved together with the Pulley A by any superstructure, or any other way from the power impelling the Supream Wheel, or part of the Engin, and the motion be made from A towards C, the Globe, or weight D, will be raised gently from the bottom to the top, whence it devolves again to animate the Clock, or other Engin, by the artifice explicated in the precedent Problem.

Secondly, the Artifice in the same third Problem, explicated in the second place may easily be applied to the drawing Sphærical weights, from the bottom to the upper most part. For let there be a toothed Wheel A B C to which there may be others made according as the thing requires; place the Pulley D E on the axis of this Wheel on which a Rope being put, let one end of it sustain the Sphærical weight P within its Box or Basket, and on the other end hang the Counterpoise N, a little lighter than the Basket P without the Globe, or weight, that from this that may be taken up. The Pestle B furnisht with a little wing lays hold on the Snags of the Pulley, and detains it against the endeavour of the weight P. Also make a certain dovetail D F in the Periphery of such bigness, that it may be equal to a quadrant of the Circle, or exceed it, in the middle of this make a long slit D F, through which the common axis D of the Wheel and of the Pulley may pass; moreover make a moving leaver H G F C made firm somewhere about the point G, with which Leaver the foresaid dovetail is linked in the point F: Then in the point A fix a spar, or bolt A K, furnisht with a pressing wing and movable about the point A, and near this bolt place a Leaver full of corners or nooks K L M N movable in the point M.

These things thus disposed, If by the motion of the Wheel A B C the weight be elevated leisurely to the top of its altitude, and

and being slipt from the Basket or Box into the groove or Channel leading it to the designed place for animation of the Clock, notwithstanding the empty basket will be moved by the power raising it, untill it hits against the Leaver CGH and lifts it up a little, and the Leaver being raised takes up together with it the dovetail FD: And this Pestle B being stretcht at length through the whole thickness of the Pulley in this part to the dovetail; in the mean while that the end H of the leaver CGH being depressed lays hold on the bolt AK and detains it, at the same time the Pestle B being lifted up without the Snags of the Pulley, the basket P, although empty, yet heavier than the counterpoise, N will turn the Pulley, and it will descend to the bottom that there it may again receive another Sphærical weight to be drawn up in the same manner.

For the counterpoise either of it self, or by making a certain knot in the Rope will raise the nooky Leaver NML, and by it withdraw the bolt AK that it detain not any longer the end H, which being loosed, the dovetail DF falls off, and then the Pestle B being sent down lays hold on the Jags of the Pulley that the attraction of the weight may be made again.

If you fear lest before the Pestle B being drove away by the Snagged teeth of the Pulley, and the Pulley with the Basket should begin to descend before the end H is laid hold on by the bolt AK; then hang so much weight to the arm GH of the Leaver as suffices to raise the dovetail with the Pestle B; and that the weight be not raised sooner than the basket ascends upwards, detain this arm GH by a certain crook or hook made after the same manner as the hook NH in the following Figure. But then in stead of the arm FC, the arm MN will be produced, that that being raised from the basket will withdraw the hook sustaining the endeavour downward of the end H which is heaviest; Moreover it will restore it to its former site ascending with the Impetus of the counterpoise N.

Also note, that when the Wheel ABC is often turn'd about in drawing of the weight, and conveys the Pestle B every where with it self, that when the attraction is finisht, the Pestle B will be found in the upper quadrant that is above the dovetail, which always certainly happens, if in the Rope or little chain of the Pulley you make little knots or buttons for that

Book VIII.

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Fig. 130. Thirdly, the same Pulley may be freed from its Pestle by another artifice; let the same Wheel B stick fast to the axis C, and the Pulley D movable thus, that it may be moved to and fro by the Axis A C; Then after that the Basket E is brought to its height, it will raise in the first place the knotty Leaver E F G fixt movably in F; and this by the little arm G H drives out the hook H N, whereby the other knotty Leaver M L K is sustain'd, to whose arm L K so much weight must be hung as is convenient, that the other arm L M laying hold on the Tube M P, joyned to the hole of the Pulley D, may draw the Pulley by the Axis A C towards C, although against the ordinary resistance of the force of the Hælix C P: And in this manner, those jagged teeth of the Pulley are withdrawn from the Pestle B, and the Basket E descends with its weight, by turning round the Pulley together freed from the obstacle of the Pestle; notwithstanding in the mean while the little arm L M touches it highly, and detains the Tube ending in the rundle, in which the contact may be facilitated by adhibiting the little Wheel, or a turning Cylinder, &c.

The arrival of the Counterpoise will make the Pulley repair to its place, for this when the impetus of the knotty Leaver M L K, lifts up the end K, it places it in the hook H N; which being done the pulley is forc'd into its place, by the pressing Hælix led about the Axis.

Hence also you must take care, in making the Pestle B, that it be not let or bore down from its little wing, deeper than the incissions, or Jags of the Pulley.

Problem. IV.

To fit an irregular finite, and disorderly moving power, so to an Engin, that it shall make a well order'd regular, or wholly equal motion.

Since Regularity and equality appears in no other motion more than in the Circular, which of its own nature seems to require equality; we shall in this place declare those things which are for obtaining this equality of motion, which truly are of great moment in Engins, especially in the construction of

those that measure time. And of these kind of Irregular powers some are perpetual, or infinite, and others finite which do execute their office to time. We shall treat of these last in this place, and of the former we shall say something hereafter; heavy things being hung at liberty whether hanging from an Engin, or some Wheel, are called regular powers, because whether they are hung high or low, they always obtain equal force or moment; notwithstanding if they are placed in some ambit of the same Wheel according to a divers site, and the same inclination, they acquire divers moments as appears from what has been said elsewhere; but 'tis needless to reduce this irregularity of weights to regularity, since that may easily be done.

Therefore irregular Powers which we commonly use in the construction and motion of Engins are Springs, that is, certain thin pieces of mettall in manner of an Hælix, or wrapt up in Spires such as are commonly used in watches, concerning which something is said before.

First, the resistance of the said thin pieces of mettall is less in the beginning while they are bent or drawn than in the end, and in like manner when they are drawn or bent have greater force, and make a greater endeavour to restore themselves into their first station in the beginning of restitution or reduction than in the end, and this force increases or decreases not uniformly, and with a proportional increase to the adductive or reductive motion, but with another certain increase or progression not as yet certainly known, of which in its place.

Secondly, if the thin piece of mettall be bowed or bent into a Spire, or larger Spieres, the bending resists less, and makes less force to reduce it self than if it be bent in lesser Spires; hence 'tis, that in this second case it hath greater force whereby it desires to restore it self, but obtains lesser motion.

Thirdly, Springs, or the same thin pieces of mettall being bowed into a Spire or wreath, may be drawn more violent either in the Centre, or in the Circumference, or in both parts together; if the thin plates consisting in the extreame which is in the circumference, the plate will be drawn by the wresting of the other extreame being in the Centre, it resists the drawing less than if remaining centrelly immovable in the extreame, the plate be wreathed about in the Periphery, the reason is, because in this second case it ought not only to out go the resistance

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ance of bending, but also the other of rubbing, or weaving of one volute upon the other, which resistance nevertheless it hath by accident.

Fourthly, Springs are made weaker by degrees by often drawing them, but they are more weakned if they never restore themselves, but if always, or for a long time, they continue drawn or pull'd; hence they have greater force in the first making of an Engin, but lesser after long using them.

Fifthly, if they remain sometime free, that is, without drawing, they recover some of their strength which they had lost before.

Sixthly, *Jo. Helmont* in his Book entituled *Med. Physic. de tempore*, *Num. 50.* affirms, That the said Springs of Clocks or Watches are wont to be more strong, or stubborn, when the North wind blows, which notwithstanding is not as yet well known to me, neither doth the cause of this *Phænomena* easily appear, unless you'll say from *Cold*, which is wont to be more rigid when the Wind is Northward.

These things being noted, the irregular force of Springs may be reduced to uniformity divers ways: First, when these thin pieces of Mettal are wont to be made every where of the same breadth and thickness, they exert their force unequally in the beginning and in the end; if the parts near the Centre be made thicker than the other, or broader with a due proportion, and then the drawing to, or lapping up being made in the Centre, the resistance will be equal and uniform in the whole drawing, or wreathing, and consequently they will make the force equal in their whole restitution, until they come to their first state, or condition; moreover on the contrary, if they are made thicker in the parts nearest the circumference, and then the drawing be made in the circumference, from the opposite reason there will be an inequality of force to compensate or amend that unequal thickness or breadth of the thin plate; notwithstanding this way, whereby the inequality of this thickness compensates, the inequality of force is not used, perhaps because 'tis more laborious, and neither is it easy to find the proportion, whereby the thickness ought to be increased gradually; yet if it were reduced into practice, it would be far more useful and certain than the other.

The second way more obvious, and used in regulating the Springs in ancient Watches, is, by an unequal pression of

the strongest part of the Spring, and that is made in a certain changable Orb like the figure of an heart, for this Orb when the spiral plate makes less force, is also less pressed from the other plate, or hindering wing ; but when it exerts greater force in like manner that force is abated, so that 'tis reduced to a certain quality ; also this way is scarcely used now among modern Artists, when notwithstanding 'tis less laborious, and, as Experience teaches, oft-times more useful than others ; perhaps 'tis despised because 'tis more simple, to deter others from inquiring into an Art which is more subtil, which they would do, if it were easier and simple.

Fig. 131. The third way, which is at this time most in use is, a Hælyx of Steel included in the Cylinder A B C D, movable about the durable axis E F ; this axis passes by the centre of the Hælix, and detains its central end firmly, and lest it should be turn'd about together with the Spire or Wreath and Cylinder, 'tis hindered by a jagged wheel G H, firmly put into an axis, and a little bolt or pestle H I, which strives against the Jags of the Wheel : To the side of the Cylinder a Cone is made, or some other such body sharpned at top like to a Top C K M, movable about the axis L M, the Periphery of this top is made in the manner of a Screw, with channellings or cavities made round it to receive a chord or chain, one end whereof is fastned in the point of the Cone K, and wound about the Cylinder, the other end of the chord is fastned to the Cylinder in D ; these things thus constituted, the inequality of the resistance of the steel spires, or wreaths, drawing irregularly is made fit or meet by the deformity of the top, which where the resistance of the spire or wreath is least, the greater Periphery being turn'd receives the chord, whereby the Cylinder is drawn about, carrying about the included end of the spire or wreath fixt to the Cylinder ; and where the force and resistance of the thin plate is stronger, the chord being then in the sharpned or lesser part of the top or cone, easily sustains that greater force by lesser distances from the centre or axis, and by allaying it, tempers it.

You see then the whole perfection of Clocks, or Watches, which consists in uniform motion, or equality, depends on the framing the foresaid cone or top ; which I desire Artists diligently to observe, and to take great care in the making of it, that the moving force of the spiral thin plate be rendered

Book VIII.

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dred every where equally valid ; neither is it sufficient, as they are wont, to try it by hearkning to it whether the sound be sharper or graver in the swiftest motion of the jagged little wheel G H, since 'tis not easy to distinguish the least difference of sound ; wherefore 'tis rather to be done some other way, and Father *Schattus* proposes two, the first is by weighing, *viz.* by a weight hung on a long arm leading the Cone about, for if which way soever the Cone be turn'd about, the same weight endeavours equally against the adduction or reduction of the Spire, the Cone or Top will be perfect.

Fig. 131. The second way is measuring by time, for, says he, the little Wheels being set at liberty in a swift and free motion ; take some very short Pendulum, and by its vibrations examin the circumvolutions of the lower Wheels, for if the circumvolutions of each wheel be in equal space of time, it argues that the cone or top is perfect : In the same manner, the circumvolutions or turnings round of the jagged little Wheel G H may be examined by a Pendulum, to wit, whether they are made in equal time, notwithstanding if there be added weight to the foresaid little wheel the motion is rendred more slow.

Problem. VI.

To mend the unequal motion of Clocks, or other Engins, by applying a Pendulum.

THe chief fault in Clocks, and all Engins that measure time, is the irregularity of motion, for no kind of Clocks to this very day is found, whose motion is so equal or uniform, that it errs not at least a minute from the true measure of time, in one day or 24 hours, although it hath been the study and endeavour of many ingenious men ; in the first place, we are indebted to *Mathew Campano* to this end, that by the accurate measure of time Geographers may obtain the knowledge of Longitude, and what proficiency they have made in it, you will understand by what follows.

Truly 'tis doubted whether any man can by application of a Pendulum, compleatly perfect the little jagged Wheels of Clocks, and take away their inequality ; therefore the Author of that famous Invention, deserves to be followed and praised of

of all Men ; and since there are divers ways of application in this kind, some whereof we have described just before, it remains that we reckon up some others in this place, either more ingenious, or also more useful.

Fig. 132. Let there be a Pendulum I L, with a wire fixt to the Axis C D, which rests on the two poles C and D, and in the middle part of its Axis, fasten here and there two little wings, or thin plates of mettall, extended according to the length of the Axis, or in an Horizontal site, above this Axis let the upper wheel of the Clock A B be turn'd, being made by a peculiar art ; to wit, let it be made in form of a Zone, with a double row of Teeth disposed to the end of the Zone in such a double order, that when the Teeth, or little Keys that stand out, being considerably distant from one another, each tooth of one row, answer to the middle space of teeth of the other row ; for so by turns they will hit against the aforesaid two wings, to wit, one tooth or little key of the row towards the right hand, on the right wing, and the other row on the left hand, on the left wing ; again, the other on the right, on the right wing, from whence are made the Altern Vibrations of the Pendulum. If then each of the two rows consists of ten teeth, in all they will make twenty ; and the Pendulum must be of such length, that each composed Vibration answers one second of time, there may be fitted on the same Axis of the wheel the Tympane F with six teeth, which will be moved by the wheel G H of 36 teeth, for this will absolve one circuit in the space of a Minute ; so that an Index fastned to its Axis, may note every second in a circle divided into 60 equal parts ; and beneath the Wheel G H, another may be fitted, which may be turn'd about in the space of an hour, and its Index may shew the minutes, moreover another which may shew the Hours, &c.

But something offers it self worth our noting in the application of Pendulums to Clocks ; in the first place, if a weight doubley or triply greater be hanged to a Clock, it is not the reason of moving it norably swifter, or the cause of making the hours visibly shorter, because in this case the Pendulum is forced more vehemently, and therefore makes greater arches in its Vibrations ; it seems that it ought to move more slowly, and to make the hours longer, if it be true that is said in the Book of Pendulums, that the Vibrations which are made in a greater

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greater arch from the same Pendulum are longest; but experience tells us, that the Hours are somewhat shorter if weights are hung much greater, and the reason is, because the wheel which is called Serpentine, or the wheel meeting with the beam of the Ballance by way doth not permit each Vibration to run through the whole Arch which they would run through, and therefore cuts them off a little shorter.

Secondly, For this reason Pendulums ought to be a small matter longer than if they were altogether at liberty, least each of their vibrations be made in a shorter time than is meet.

Thirdly, You ought not to use a string or little chain, because they will bend, but a wire, or in greater Pendulums, a rod of Iron, or other Mettal.

Fourthly, Since in these kind of Clocks the augmenting or decreasing of weights signifies little to the swiftness or slowness of motion, but the swiftness or slowness depends almost wholly on the length or shortness of the Pendulum; therefore that Clock may be reduced to the just measures of Hours, the Globe, or Ball, ought to be fixed to the lower end of the Rod, in such manner, that it may be raised or depressed, and that may be done if there be a screw made on the end of the Rod, which is engrafted to the Globe more or less, and binds it very well that it slide not down, which inconveniency may be prevented by another concave Screw P, which keeps the Globe away in the same place.

Fifthly, 'Tis better to hang a heavier weight to a Clock, or make use of a stronger Spring, and to apply a Pendulum a little the longer.

Sixthly, The Vibrations ought not to be too great, but the Pendulum ought to swing backward and forward to the height of 30 or 40 degrees in its arch.

Seventhly, Clocks made with Pendulums, require much greater weight or stronger Springs than others, which are regulated by the ordinary simple poisers, so that sometimes a triple weight is required to it, than is required to a Clock without a Pendulum; nevertheless for divers reasons, according to the manner or fashion, a Pendulum may be fitted, it may require more or less weight in the precedent artifice, unless the little wings of the Axis C D be made long, it will require a great weight; as appears from the principles of Mechanicks.

Eighthly,

Eighthly, Greater Clocks which are furnisht with greater Pendulums, in like manner require weights in the same proportion, or also in a greater than the times of the Vibrations have, or which is the same, in subduplicate proportion of the lengths of the Pendulums; for Example, let a Clock have a pendulum of 36 inches, or 3 feet, which makes each Vibration in one second, and another with a pendulum of 9 inches, which absolvs the vibrations in half a second, so that in one hour that makes 3600 vibrations, and this makes 7200; since the pendulum of the first Clock is quadruple of the other, to agitate it, is required a quadruple force or weight; because it ought to move but doubly slower, also the Serpentine wheel, or that which incites the pendulum, must be moved doubly slower, and therefore the weight hung to the lower wheel will have a double weight, therefore a double weight suffices to move a pendulum of quadruple length through like Arches; for a double weight, if it have over and above a double poise of another weight, is equivalent to a quadruple weight.

Fig. 133. Notwithstanding 'tis to be Noted, if the longer pendulum be inforced in a point proportionally distant from the centre of the pendulum, a weight as little again will suffice to move the long pendulum, as if the pendulum A C, receive an impulse from the upper wheel in the point B, and another longer pendulum D F, receive an impulse in the point E, and let the proportion be the same of A C to D B as of D F to D E, a weight doubly lesser is required to move the longer pendulum than to move the shorter pendulum; for if the disposition of the wheels be the same, or the velocity the same as the upper wheel, an equal weight is required as appears, but in a longer pendulum the upper wheel is moved doubly slower, and so the weight hung to the Clock hath a double poise, therefore a weight doubly less suffices. But if the pendulum D F be impelled in G, so that D G be a mean proportional between A B and D E, than an equal weight in each Clock is required, and only double the weight is required in the Clock of the pendulum D F, when the pendulum is incited in the point H, so that D H be equal to A B, and the Globes C and F are supposed of equal weight, but if the weights are unequal, then their proportion ought to be had, which may vary diversly.

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Book IX.

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Problem. VII.

Another way of fitting a Pendulum to a Clock.

Fig. 134. **H**ere we will describe the way most in use of fitting Pendulums to Clocks, the serpentine or encountring wheel, must be placed in an Horizontal site, and the beam of the Ballance also stretcht out Horizontally on the same; the wheel furnisht with jagged teeth, must have its number unequal to this, that two little flaps, or wings, of the Beam of the Ballance, may lay hold on the teeth by turns, according to the usual manner, which little wings ought therefore so to be joined to the beam of the Ballance, that their planes make a right angle, and the Axis of the beam ought to be extended precisely through the centre of the Wheel; but because if the Pendulum be immediately join'd to the beam of the ballance, its weight will burden it too much, therefore a handle is added to the beam, boarded through in the extream point, to which hole is fixt a rod hanging at liberty that it may easily agitate.

But you must take care that the lower little arm possess a middle site between each little wing of the beam of the Ballance, lest one vibration of the pendulum be greater than another, and make the motion very incongruous and lame; in the rest observe the precepts already delivered; some fix a Globe unmoveable on the end without any Screw, moving the centre of the Spear or Wire, they raise it or depreß it to reduce the vibrations to the exact measure of time, for when the centre is raised, the pendulum runs through a lesser arch, and sooner dispatches each vibration, specially because 'tis resisted by a lesser impulse, and it makes the vibration slower, if it be depreßed for the contrary reasons; yet you must take care that the centre be not beneath the axis, nor that it be elevated much above it; lastly, the length of the little arms are determined by practice, and by the wheels.

Problem. VIII.

To amend the Irregularity of all Clocks and Engins, measuring time otherwise than by the manner of Pendulums.

I Know some have not been wanting, who are willing to adopt Pendulums to watches, or portables Clocks, nevertheless they laboured in vain; for the smallness of the Watches, and the diversity of their Scituations, with the continual agitation of the pendulums, while they are carried about, cannot easily admit them to vibrate uniformly; and although the pendulum may be so fitted, that being librated between many circles or rings, after the manner of a Sea Needle, it may always obtain a perpendicular site; however the agitation of the whole watch will make the vibrations of the pendulum to run sometimes in this, sometimes in the other part, hindering their equality altogether, besides that, the space which the beam requires, is much greater than the magnitude of Watches will conveniently admit; wherefore perchance more parly, the whole watch with its pendulum appled to it after one of the foresaid prescriptions, may be hung within 3 or 4 little circles, which may easily be included in a Sphærical case of the Watch.

Since therefore the application of Pendulums to these kind of Watches, or other portable Engins, are either useless or altogether difficult, the illustrious *Hugenius* (for his new Invention, now known to all the World) hath found out another way, which I could not pass by in this place, it being very profitable and ingenious, therefore accept it as taken from Letters of the same Author.

The Mystery of the Invention consists in a thin plate of metal or spiral crest, having fastned to it at the lower end a Catsgut String, or an Instrument of an equal weight, but greater and more ponderous than is wont, and movable of its own accord to and fro upon its points; and the other end is fastned to a little part or covert sticking up above the upper part of the Clock, which being once vibrated to the tongue of the Ballance of the Clock, compresses and releases its spires one after another, and drawing to it self a little help coming from the wheels of the clock, maintains the motion of the Instrument or Ballance so truly, that although it makes greater or lesser

Book IX.

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Fig. 134. In the figure of the former Clock the plane is A B, the circle of the Ballance, or compass about the tongue of the ballance C D, its axis or lance E F; the wing or spring turn'd into a spire G H M is fastned to the spear of the ballance in M, and to the thin plate of mettall on the upper plane of the Clock in G, so truly, that all the spires of the spring cleave to these two props hanged up in the air, touching nothing beneath: N O P Q is a certain covering, or propping, in which the other point of the ballance is turned: R S is one of the toothed Wheels of the Clock, having a certain motion of the poiser imprest on it from meeting with the next wheel, and this wheel R S is folded into the Tympane T, made fast to the axis or spear of the poiser, whose motion is by this means as much maintain'd as there is occasion.

This Invention of *Hugenius* may be used not only in Watches, and portable Clocks, but also in others which are put into motion by hung weights; and to which he adds, That a clock made by the foresaid Artifice may be serviceable in finding the Longitude at Land and Sea, which I am not easily induced to believe, for neither is the inequallity of motion of Clocks more corrected by this Invention than by Pendulums, as you may easily understand by what is said, nevertheless 'tis very useful, because it may be fitted to portable Clocks, or Watches, which cannot suffer a Pendulum.

Fig. 135. I observe that the spear of the ballance E F may agitate, and unless I am mistaken, more beneficially by a Zone or double wheel with smooth teeth, or little keys after that manner, whereby a pendulum agitates in the fifth problem, to wit, if the little keys C, D, G, H, &c. by turns, or one after another, hit against the two little wings A and B, here and there fixt to the same spear or lance; for since this spear ought to be much thicker and stronger than commonly they are wont in common Clocks, and more resists the impulses of the wheel S R, by reason of the spire G H endeavouring against it, the poising wheel commonly call'd Serpentine is not so useful, which is wont to agitate the common spear of the Ballance.

Problem. IX.

A Clock that makes no Noise, and yet hath a Pendulum.

Fig. 136. **I**T will not be unpleasant in this place to describe a kind of a Clock which we found in Father *Millet's* third Book of Statics, or art of ballancing, *Prop. 59.* where he hath these things.

This kind of Clock, or Watch, is most usefull, because no found of the Poiser is heard, and therefore may be used in a Bed-room without fear of disturbing ones rest.

The Lord *Setale* hath had many of this kind made, and the Artifice was thus: The Clock consists of 4 wheels, and one axis furnisht with little wings or Pinions.

The first wheel was furnisht with 96 Teeth, and dispatcht half a circulation in an hour.

The second had in the axis 12 little Teeth, and in the circumference of the wheel, it had 72 little Teeth, and it accomplit 4 circulations in one hour.

The third had 6 little teeth in the axis, and in the circumference 60 little teeth, and finisht 48 circulations in an hour.

The fourth had 8 little Teeth in the axis, and in the circumference 80, and finisht 360 circulations in an hour.

The axis furnisht with wings which is described in the Figure *e e*, had 8 little teeth, and finisht 3600 circulations in an hour, and since every circulation made one compounded vibration, there was 3600 compounded vibrations, and 7200 simple ones; one compounded vibration is equal to a second Minute, and a simple one to half a second minute, the length of the pendulum was 9 inches.

The whole Artifice consists in the axis *B C*, and in the handle of the pendulum *H I K*, which may be turned about the point *G*, as about an axis, and the point *K* was ingrafted in the point *6* of the axis, furnisht with rings, which axis while it turns, inforces the arm *K I*, and draws it in by turns; which you may easily conceive, if the arm *K I* be at right angles with the axis *B C*, and be ingrafted in the point *6*; the rest may better be conceived if the thing be put into Execution, than can be exprest in words.

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Problem. X.

To determine the number of Teeth and Wheels in Clocks which have Pendulums.

THis practice ought not wholly to be neglected, which is most useful in directing Artificers, especially since it also contains a method of beginning, and reckoning the number of vibrations and circulations of wheels, which is very necessary in the construction of all other Engines.

The foresaid Author began these reckonings, together with the foresaid method in divers forms of Clocks, beginning from a Clock which consisted of two wheels only; for although it is difficult to fit that pendulum, nevertheless if it be accomplished it will be very exact, since the meeting of many wheels induce always a greater inequality in motion.

Fig. 137. In the first place therefore (saith he) let there be two wheels, the first or lower of 120 teeth, which is supposed to finish two circulations in hour, wherefore it will be equivalent to a wheel of 240 teeth: The second wheel hath a little wheel of 5 teeth, wherefore while they pass through 5 of the teeth of the greater wheel, the second finishes one circulation, therefore you must know how many times 5 is found in 240, which you will know by Division, and the quotient will be 48, wherefore the second wheel makes 48 circumvolutions in one hour: And it appears, that the second wheel of 35 teeth, each of which effects two single vibrations, since it touches the poiser twice; wherefore each circulation makes 70 vibrations, multiply 70 by 48 and you will find 3360 single vibrations in an hour, the Pendulum will be Feet $3\frac{1}{2}$, and somewhat more.

Fig. 138. I will propose another not unlike the precedent: Let the same wheel have 120 teeth which will make two circulations in an hour, and therefore will be equivalent to a wheel of 240 teeth: The second little wheel shall have 6 teeth, divide 240 by 6 and the quotient will be 40, the second wheel then will be turn'd round 40 times in an hour, and shall have 45 teeth; and because, as I said but now, each tooth touches the poiser twice in each circulation, this number will be doubled

led and will make 90, which number multiply by 40, and you will have 3600 single vibrations in an hour, that is, each single vibration will be equal to a second minute; the length of the Pendulum must be 3 feet 3 inches and $\frac{2}{5}$ of our English feet.

Or if instead of the 6 teeth of the little wheel you put the teeth of the little wheel 5, for then the second wheel compleats 48 circulations in an hour, and there will be 4320 vibrations in an hour, the length of the Pendulum will be about two feet.

In the like manner, if there be given the first wheel making two circulations in an hour, and of 150 teeth; the second wheel, or that which encounters with it, shall

Fig. 139. have a little wheel of 5 teeth: Wherefore the division being made of 300 teeth (which are in two circulations) by 5, it will make 60 circulations: Suppose 60 teeth in the second wheel, that is, 120 vibrations in each circulation, it will make the number 7200, and the Pendulum about 9 inches, that is, each single vibration will be equivalent to half a second minute.

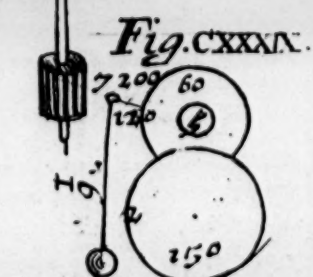
The same things being observed, except that the first wheel compleats only one circulation in an hour, you will have the number of vibrations 3600, and the Pendulum will be 3 feet, that is, each vibration will be equal to one second minute.

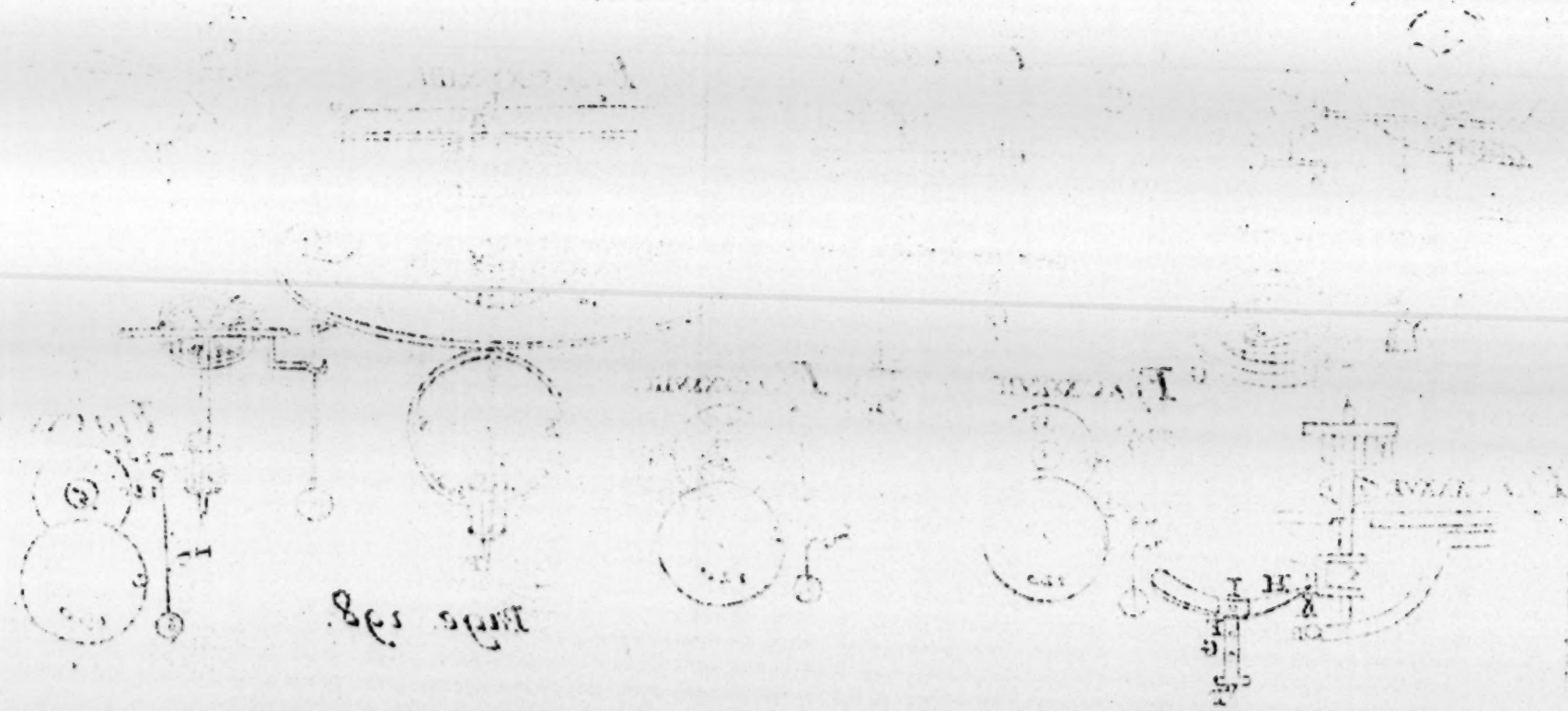
Which Examples I have put only, because you may learn the method of finding out other numbers, which shall seem more fit.

A Clock with three Wheels.

You can scarcely make Clocks with Pendulums which shall have only two wheels, unless you make the Wheels very great, and abundance of teeth: Wherefore the greater are commonly made of three Wheels, and the lesser of four: I shall exhibit in this place some numbers: A Clock hath

Fig. 140. 3 wheels, the first of which hath 112 teeth, and the second little wheel 7, the second wheel hath 60, the little wheel, or axis of the third wheel hath 8 teeth, the meeting wheel 15, you will have the number of Vibrations thus, Divide 112, the number of teeth of the first (which in each hour is once turn'd about) by 7, to wit, the axis of the second, and you will find the second to be turn'd about 16 times; and the second hath 60 teeth, wherefore multiply 16 by





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be 60 and you will find the second in an hour is of the third, and its convolutions, and its vibrations, multiply 30 times, and each equal the Pendulum must be

The same is better
of teeth, the axis of
third 6, the third
great Clocks.

The 3 following
ans in an hour, the
rit, the going and
9 inches.

Order of Revol.	Circumvo- lutions.	Vibrations.
3	144	
2	15	
1	1	

Length of Pendulum 9

the succeeding
tions 7600 and
8 inches and 4

Order of wheels.	Circumvolutions.
3	200
2	20
1	$1\frac{1}{2}$

length of Pendulum 8

by 60 and you will find 960, therefore it passes over 960 teeth of the second in an hour, which number you must divide by 8, the axis of the third, and you will find the third to make 120 circumvolutions, and it hath 15 teeth which make 30 single vibrations, multiply 30 by 120 you will have 3600 single vibrations, and each equivalent to a second minute, the length of the Pendulum must be about three feet.

The same is better done by other numbers : Let the first have 96 teeth, the axis of the second 6, the second 45, the axis of the third 6, the third 15, and this length of 3 feet is best for great Clocks.

The 3 following numbers give the number 7200 vibrations in an hour, that is, 2 vibrations in one second minute, to wit, the going and returning, and the length of the Pendulum 9 inches.

Vibrations 7200.			Vibrations 7200.			
order of wheels.	Circumvolutions.	Teeth of wheels.	Circumvolutions	Teeth of wheels.	Circumvolutions	Teeth of wheels.
3	144	25 5	144	25 5	144	25 5
2	15	48 5	12	60 6	$14\frac{2}{5}$	50 5
1	1	75	1	72	1	72
Length of Pendulum 9 inches.			Pend. 9 inches.		Pend. 9 inches.	

In the succeeding Table the numbers described give the Vibrations 7600 and 10000, with the Length of the Pendulum 8 inches and 4 inches and $\frac{2}{3}$.

Vibrations 7600.					Vibrations 10000.			
order of wheels.	Circumvolutions.	Teeth	Circumvolutions	Teeth	Circumvolutions	Teeth	Cir.	Tee.
3	200	19 6	200	19 5	200	25 5	200	25 5
2	20	60 6	20	50 6	20	50 5	20	50 5
1	$1\frac{1}{2}$	80	2	60	$1\frac{1}{3}$	75	$1\frac{1}{4}$	80

Length of Pendulum 8 inches.

Pend. 8 inches.

Pend. 4 inches $\frac{2}{3}$ $1\frac{2}{3}$

The

The following Numbers are for a Clock, which makes 10800 Vibrations in an hour, or 3 in one second minute, the length of the Pendulum 4 inches and $\frac{1}{4}$, and others also, as may be seen in the following Table.

10800		10800		1440		11400		11400		10944		9600	
216	25	216	25	288	25	300	19	300	19	288	19	320	15
	5		5						5		5		5
22 $\frac{1}{2}$	28	18	60	28 $\frac{1}{2}$	50	30	50	25	60	24	60	26 $\frac{1}{3}$	60
	5		6		5		5		6		6		6
1 $\frac{1}{2}$	75	1 $\frac{1}{2}$	72	2	72	2	75	2	75	2	72	2	30

The following Numbers are for a Clock with 4 Wheels, the number of Vibrations in an hour are 10800, to wit, 3 Vibrations answer one second minute, the length of the Pendulum is about 4 inches $\frac{2}{3}$.

10800		10800		10800		10800	
360	15	360	15	360	15	360	15
	6		5		6		6
60	36	60	30	60	36	60	36
	6		6		6		6
7 $\frac{1}{2}$	48	9	40	8	45	8	45
	8		6		8		7
1	60	1	54	1	64	1	56

These Tables were made by the foresaid Author, wherein the Printer had committed some Errors which we have amended, that they may be useful to Artificers.

If in the last Table you take the numbers proposed, changing only the number 15 of teeth of the upper wheel, and in its place using a wheel of 20 teeth, you will have a Clock which

Book IX.

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which will compleat 14400 Vibrations in an hour, to wit, 4 in one second minute, and the length of the pendulum will be Inches $2 \frac{1}{4}$; nevertheless because many Artificers will have the meeting wheel to have an odd number of teeth, they observe the precedent numbers, to wit, so that only the last wheel but one which finishes 60 circulations in an hour hath 48 teeth instead of 36 teeth, and makes the same number of Vibrations 14400.

Wheels are divided many other ways, and the Clocks are commonly furnisht with Pendulums; some are so disposed, that the serpentine, or encountring Wheel, is turn'd round 60 times in an hour, and is furnisht with 30 teeth, and finishes two vibrations in one second minute; or hath 30 teeth, and finishes one vibration in a minute, then the number of the teeth themselves inscribe the minutes which appear conspicuous through a round hole, or through a little opening made in the front of the Clock.

Problem. XI.

To correct perfectly the inequality of motion of Clocks, or other Engins that measure time, having Pendulums, by applying a double Pendulum, and by Cycloides.

ALthough a Pendulum applied to a Clock (as we have said) effects this, that if the impulsive cause of motion of the wheels be too swift, or too slow, its vibrations tempers it, each of which when they measure a determinate time, either they agree to the too much celerity of the wheels, or they stir up and excite their heaviness and dulness, whence for the most part the irregularity is taken away; notwithstanding because while the Pendulum resists the unequal impulses of the wheels, their vibrations must needs contract some irregularity to themselves, so that some make their excursions thro' greater and others thro' lesser arches; and it appears by what has been said, that those Pendulums finish their arches in shorter time which make the least arches, and those in longer which make greater or larger arches: Hence 'tis, that by application of a Pendulum all the Irregularity is not wholly corrected, unless the Clock be so fitted that the vibrations be truly regular and uniform.

And this irregularity of Vibrations may proceed from a threefold head; the first is, the various temper of the air thro' which the globe passes, for if it be thick it resists more, if heavier, the motion is not only consequently hindered by the greater density, but also the weight of the globe is rendered less ponderous, that therefore they have less strength to cut the air, and it renders the motion of the wheels and the *Impetus* more faint and weak. The second is, the impulsive force of the wheels, or other power, continuing the vibrations, which if it be irregular, induces in like manner at least some, if not all, the Irregularity in the vibrations, and these two heads may be referred to outward causes. The third is from within, or from the nature of the vibrations themselves, which are, as we have said, that if a globe fall by its own weight, in swinging it will make many vibrations, yet they will not all be of a like continuance.

The irregularity of Vibrations which proceed from the first head may wholly be taken away, if the Clock with the Pendulum be included in a case of glass, or such like receptacle, wholly unpassable to the air (which how to perform we shall shew hereafter) wherefore it remains that we speak to the two other.

To the Irregularity of the third head, which is as it were inbred in the simple vibrations themselves, a remedy seems to be found by the industrious *Hugenius* by the following ingenious practice, the whole Art consists in a double arch of the figure of a Cycloid, within which the Pendulum agitates.

Fig. 141. Let the Pendulum be A B, which is agitated to and fro by indifferent arches B C, B D of 20 degrees, and let this Pendulum hang by a thred or small cord A E of one inch more or less, according to the length of the Pendulum, whose remaining part E B must be stiff; dispose here and there near the centre A two bowed thin plates of mettall A G H and A F I, so that they touch the lines A D, A C, in the points F and G, and the curvity ought to have the figure of a Cycloid; so it will come to pass that if the Pendulum make greater vibrations, and runs out beyond the lines A C, A D, it will touch the Cycloid in the points F and G, and its length will not any longer be A D but F D, and so when the Pendulum is made shorter, its vibration continues less time: But why the Author chose rather the figure of a Cycloid than another Curve doth not sufficiently

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ly appear, nor doth his Demonstration seem to be lawful, whereby he pretends to shew by this Cycloid that the length of the Pendulum is made lesser and lesser successively, while it hits against the thred A E, and that that lesser length precisely compensates the greater length of time of the vibrations which are made by the greater arches.

The manner of describing the Cycloid, according to the Author, is two fold: First, describe a Circle whose diameter A B is equal to half the length of the given Pendulum; take in the circumference any number of equal parts both ways from the diameter as A C, C D, D E, E F, and A G, G H, H I, I K, and join the parallel lines C G, D H, E I, F K, then make the right line L M equal to the Curve or arch A D F, and divide it into as many equal parts as there are in the arch, to wit, into 4 parts, one of these parts of the line L M transfer from C to N, and the same transfer from G to O; moreover two of these parts L M transfer from D in P, and from H in Q; likewise three of them from E in R, and from I in S: Lastly, all four from F in T, and from K in V, and by the points A, O, Q, S, V draw a line, and also by the points A, N, P, R, T, and they will be portions of a Cycloid; between which the Pendulum must be hung from the Centre A; the right line L M which is to be equal to the arch A D F, he teaches to find in this manner: Make X Z equal to two chords, subtending the arches A D, D F, then take X Y equal to the Chord A F, of the whole arch A D F, take the third part of the difference Y Z, that is Z A, and add it to X Z, and X A will be a right line equal to the arch.

The second way is Mechanically; on a plain Table, place a Ruler A B half an inch in thickness, make also a little wheel or cylinder of the same thickness C D E H, whose Diameter make equal to half the length of the pendulum; then a thred or string F C H E being fastned in the point F of the rule, and in some point E of the Cylinder, so that part of it be wound about the Cylinder, and the other part extended on the side of the rule F C; in the same Cylinder fix an iron stile D I, which shall descend a little below the lower base, and exactly correspond to the circumference of the Cylinder; these things thus disposed, if the Cylinder turn about on the side B A, towards A, so that the string be always wholly strecht, the stile with its point I, will describe the cycloid line I K, and in the same

manner, you may describe another like and opposit unto it, and you will have the figure M K I, which represents the space between the two crooked pieces of thin mettall, between which the pendulum ought to agitate, so as to make all its vibrations in equal times.

Another late invention of *Mathew Campanes* consists altogether like to a double Pendulum, which is so fitted to the Clock, that one of them moves and makes a certain number of vibrations, the other resting, and by turns while the first resteth the other finishes the same number of vibrations; and in this manner, 'tis agitated by one after tother, that as soon as one resteth, the other begins to move; for if a pendulum of its own accord and proper weight falling from some certain height of its arch, make 100 vibrations in the space of one minute of an hour; 'tis certain that another exactly like the former will effect the same number of vibrations in the same space of time, provided it fall of it self from the same height; to wit, the impediment being removed in the same manner which detain'd the pendulum from falling from that Altitude; wherefore if two pendulums are so fitted in a Clock, that they are both every where alike, and falling from an equal height finish 100 vibrations in one minute, they will move one after another, nor will one begin to move until the other has finisht 100 vibrations, and no irregularity can intervene in the measure of motion, since each compleats 100 vibrations in one minute precisely.

And the Clock may be so disposed, that while one pendulum makes its vibrations, the other pendulum not only rests, but neither any of its wheels of the Clock are moved, besides some one designed for the purpose, that as soon as the other hath made 100 or 60 vibrations, it removes the impediment which detain'd both the pendulum and the Clock, and detains the pendulum first in agitation to rest at the same instant that the other together with the Clock begins to move; then again, the Clock with the pendulum resteth the impediment being removed from the motion of the other pendulum.

This may be done many ways, as any one instructed and exercised in Mechanicks may easily understand; the Author shews one way, which because he hath not sufficiently explained it, 'tis in vain to describe it here.

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double pendulum to be most exact, and scarcely to err one minute in an whole day, that is, in 24 hours, if it be well kept in some Chamber, and be placed in an unmoveable site; yet if you make use of it in Navigation to find the Geographical Longitude, I cannot esteem it wholly to satisfy what is desired, for two Reasons; first, because it can scarce be in the agitation of a great ship, but the whole Clock must conceive some motion, or at least a light shaking or trembling in it self, although it be artificially fixt on movable poles, or hangs on movable circles; from which trembling or shaking, the vibrations of the pendulums must needs suffer some irregularity.

The second reason common to all kind of pendulums is, because while the pendulum is moved together with the ship, it makes not a circular motion, but another motion mixt of a circular and a right; yea, if the ship besides an Horizontal motion be agitated by other motions, chiefly upwards and downwards, as happens many times in an unquiet Sea, the motion of the Pendulum will be mixt of a Circular, Horizontal, and of other motions both right and crooked, nor at any time uniform, from whence it comes to pass, that while the centre of the pendulum is irregularly moved, its vibrations will be irregular, and it will run through some times greater and some times lesser arches, or rather crooked lines, and altogether unlike between themselves, as we have shewn before.

Problem. XII.

To reduce the continual moving, and irregular Powers of Clocks and Engins, to a regular and uniform motion.

Since in the preceeding Problem we have taught ways and means whereby the finite and irregular motions of Powers may practically be reduced to equality of motion, nothing seems now to be wanting, unless 'tis to shew how to obtain a motion equal and uniform in powers infinite or continual, which otherwise of their own nature are irregular; which, if it be done, we shall attain to a motion continual, and altogether equal; nevertheless I do not mean that continual motion which is altogether mechanical, or purely artificial (of which in its place) but the other which is called *Physico-Mechanic*, because that it partly consists of Art, and partly of Nature; for since no moving

power seems to be continual or perpetual, unless it be natural, or depends immediately on a natural cause, as we shall manifest hereafter, and these kind of natural powers or virtues in nature keep not always an equal order; it is requisite to find out an art whereby we may effect that their force, although unequal, may nevertheless be serviceable to the perpetuating of a motion equal, and altogether uniform.

Therefore I call all those perpetual moving powers, or natural and irregular, to which we are apt either immediately or mediately to apply new weights, or regular powers, within some finite and determinate time successively, and always to the Engin being once made.

And all the industry and art which is to used in this matter, may easily be gathered from what we have said in Problem the 5th, for if we suppose a Clock to be made, whose motion according to the rules prescribed just before is absolutely uniform, and it should go so for eight days by some weight hanged to the lower wheel, that in that space of time, it shall want no help, if then within that same time of 8 days an infinite power, or a perpetual natural one be artificially applied, that shall be fit to raise another weight equal to the former, and to deposit it in the place of the former, so that forthwith the weight of the Clock likewise shall descend to the bottom, and be placed in the subjected channel, the Clock will be moved again by that new advanced weight, according to the artifice in Problem the 5th. aforesaid, and that will also keep it going 8 days, it is plain that the motion of the Clock will be equal and perpetual.

But Note, that you must use two weights at least, one whereof must be hung to the Clock, while its regular motion moves forward, the other by an irregular power (suppose Wind, Rain, Heat, Drought, &c.) is substituted in its place, before that hath discharged its office.

Moreover these two weights ought to be Sphærical, that one may easily succeed the other, the devolution being made by a channel, or plane, somewhat declining, as in the same 5th problem is shewn.

Lastly, 'tis convenient that the motion of the Clock be long enough, and lasting, before the weight descend to the lowest place, for this reason, that the natural powers may serve turn a sufficient time in the interim, that the other weight that comes in

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in place of the former be drawn up; for although the fore-
 said power be perpetual, yet it acts not always, or at least so
 little sometimes, that although at some times it be more strong,
 oft-times nevertheless a time may be expected for some hours,
 or also days, wherein force convenient may be attained by the
 successive and irregular series of natural causes; that you may
 more clearly understand what is meant when we speak of per-
 petual motion, for then we describe various perpetual motions
Physico-Mechanic, from whence it appears of what use na-
 tural powers are, and by what art they are applied, that their
 force although irregular may notwithstanding perpetuate a re-
 gular motion to any Engin; I will offer only one Example in
 this place, by which you may easily judge of the rest. 'Tis
 already known to Artificers, that by small Breaths, or from the
 smoak of a Kitchen Fire, spits are wont to be turn'd, that is to
 say, dispose in the centre of the Chimny (which if it be Cy-
 lindrical it will be the better) a cross, or some wheel, furnisht
 with wings made of Tin, in the same or like form as is before
 described, for so while those wings hit obliquely against the
 Smoak, they carry the wheel about, and if there be in the axis
 a toothed Tympane, it conveys that together with it self, by
 which means it moves other wheels annext to it; a weight
 somewhat Sphærical put into a little Basket, may be raised to
 a certain height, and there put down according as we have
 said at *Problem 5th*. And to raise this weight which is fit to
 animate the Clock in motion 24 hours, it will not be needful
 that wood be always put on the fire, but a fire a few hours
 will be sufficient each day, if the Clock which is to animate by
 the weight raised by the Smoak, be proportioned to that weight.
 Wherefore in this, and any other like artifice, first you must
 examine how much weight may conveniently be raised by a
 natural power in a limited time to a perfixt height, and then
 make the Clock or Engin proportioned to such weight.

What we have said concerning Smoak, may take place in
 Wind blowing, and Wings impelling, which will raise weight
 by annexing wheels, also if any one in a City, or the Gate of
 an House, dispose a threshold, or little Bridge, with an occult
 leaver, or a spring of thin mettāl plate a little elevated, so that
 by the entring or going forth of Men, of Horses, and of Cha-
 riots, a weight may be depressed oft-times in a day, from each
 force a weight of some bigness may be raised a little, and so
 by

by repeated motions may be drawn to a designed height for the perpetual animating of any Engin.

Problem. XIII.

A Clock animated, or going by Sand, persevering in motion many days, and shewing the Hours, and also Striking.

After the application of weights, or moving powers, we come to those Engins, or measurers of time, in which the circular motion is most apparent, and since there are many Hour-glasses that belong to perpendicular motion, or to an inclined plane, it remains for the perfecting of them, that we shew how (approaching to circular motion) it may be effected that they may turn themselves by motion of their own accord after the flowing or running of the Sand, and that not once, but many times one after another, that therefore we may not only be freed from the inconveniency of attending the last flux of the Sand, while we are conversant in any other business, but also that it may not want any help of the hands for several days, and each turning about may successively shew the Hours, or likewise Strike: Mark what follows.

Fig. 143. Suppose A B an Hour-glass with Sand, such as is commonly used, in the middle whereof fix a transverse axis G H, and in an Horizontal site, and to the same axis let there be firmly fitted two Pullies, or rather Cylinders here and there, movable with the axis by means of weights Q and R hanging from them; above the Hour-glass make another Horizontal axis I K, movable about the poles I K, to whose side annex an immovable arm L M, with a weight M affixt to its end; and in the middle in like manner, let another little arm N O parallel to the former descend, which may be detain'd in its extrem part O, or rather elevated together with the weight M, by a little wing standing out from the upper base of the Sand, so that being hindred by the weight M, the Sand cannot be wholly turned by the weights Q and R, notwithstanding it will remain in a site not altogether perpendicular, but somewhat inclined; and the weight M must be so proportioned to the weight of the Clock, and also to the weights Q and R, that it may be detain'd in the said inclined site, untill all the sand be descended from the upper glass A into the lower one B, and when all the Sand is run into the lower glass B, it will obtain greater

greater weight
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the weight M
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Fig. 144 M

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greater weight, that therefore while the Sand endeavours to be placed in a perpendicular site, or in the line of direction, the weight M will rise higher, and at once will free the little wing O from the little arm N O, from whence follows the turning of the Hour-glass by means of the weights Q R, and the lower part B will be placed in the upper part, and will be detained by the little arm N O, by means of the little flap or wing P, untill the Sand is again run out; for then it will again be turned as before, and so successively until the weights Q and R are quite descended; but because the little Cylinders C E, on which the ropes sustaining, the weights Q R are turn'd about, may be of a small bigness, and because after every hour they make but half a revolution, it appears that the motion of the Clock and the turnings may be extended to many hours.

But if you would fit an index to shew the hours, that you may easily obtain by means of two little teeth, fixt on the end G of the axis G H and opposite to each other, which successively and by turns one after another, every turning of the Hour-glass will move forward the wheel G T, furnisht with so many teeth as there are hours described in the circle, which may be noted by a standing index fixt in the centre of the same wheel; but if in like manner you affix an hour wheel in a convenient place to the same Engin, which may be moved forward by means of some toothed Tympane, or wheel, by the same axis, you may cause the number of hours to be heard by striking on a Bell.

Many other ways the index may be fitted to the same Engin, and the striking of the hours may be made, as will appear by what we shall shew hereafter, when we shall treat of the indexes of Clocks, and their striking.

Problem. XIV.

A Clock moving by the Consumption of Oyl in a Lamp.

Fig. 144. **M**AKE a Lamp whose part A B entertaining the Oyl, is like a Column or Cylindrical, shut close every where, except in its lowest part C, where the Oyl enters slowly through a little opening into a vessel annex C L, while the other Oyl is consumed by the flame L; in the foremost part

E e

I N

I N make a certain channel, and solder or glue it to the fore-said Cylinder, within which on the upper part make a secret or hidden pulley I, with an axis E F, presenting or conveying on the outward visible face the index of the hours described in the circle G H.

These things being done, put Oyl into the Lamp, or Cylinder A B, upon which let a cube D of light matter (as Cork, or Wood) swim, and to this you must fasten a thred, or cat-gut D C G I M, viz. that it may descend from the upper superficies of the Oyl to C, and being put about the little pulleys C C, it may ascend to I, and be folded about that pulley; and lastly, let the other end M sustain a weight, yet of less gravity than to draw downwards the cube D, which must always swim upon the Oyl, and while the Oyl consumes, it descends with the Oyl, and draws the thred, or Cat-gut, with the weight M, and turns the pulley I, together with the hour Index.

Note, That the magnitude of the little pulley I, must be proportionate with the descent of the Oyl, and of the cube D; wherefore we must observe how much the cube descends in one hour, to the end that the little pulley moving, the index I may be moved orderly.

Moreover the receiver must be uniform, and of one thickness, and must make use of the same number of threds that the Oyl may be consumed uniformly, and the Lamp may be fill'd with Oyl, either by a little door, or wicket, beneath C, or by some hole in the upper base of the Cylinder A, which afterwards must be diligently fenced from the Air entring in with a Screw.

If the axis of the little pulley I be so fitted within the Cylinder A B, that its end F stick out on the out-side by a hole made in the same Cylinder, and turn about the Index, you will obtain the same effect without the channel on the exterior part I N, which is made to cause the artifice to seem occult and mysterious; but that hole must be so fitted to the movable axis within it E F, that there appear no admittance for air into the Cylinder A B, for if there be, the Oyl will wholly descend, and be poured out without the vessel C L.

Also the index of the hours may be made in the upper base A, of the Cylinder to fit, so that the base it self be for the hour circle, which may easily be obtained many ways, as will appear to any industrious Artificer.

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Book IX.

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Fig. 145. T

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Lastly, Besides the circle and the hour index, there may be applied a toothed wheel, by whose means the hours may strike; and if to make it more ingeniously, you would place a little Bell within the Lamp to give notice of the hours, you must folder or glue an open tube spirally to both ends of the inward superficies of a concave Cylinder, descending about the Cylinder; and through this tube, or channel, descends the Oyl while it wafts by degrees, and a globe of light matter swimming on the Oyl within the tube; then all things being so fixed, that in each hour the motion of the Globe in descending, finishes one whole spire, and then it hits against a pestle, or some flap, or wing, which looses the movable wheel from the weight, as is wont to be done in common Clocks with wheels, so after the finishing of each space of the spires, the Globe unloosing the same wheel, causes new strokes of the hours on the Bell.

Problem. XV.

To make a pulley Clock, or a Clock of meer pullies without any toothed wheels.

Fig. 145. **T**His artifice is proposed by Father Schottus, lib. 9. *Tecnic. Cap. 10. Prop. 47.* Let there be (says he) a little pulley A B about its axis, or also with a movable axis, to this join the perpendicular M N P, by the artifice in Problem the 3d, and that by means of a little rod M A; from the little pulley A B, suspend the pulley C D, by means of a perpetual knotty little chord, whether those knots be made of firm little balls disposed or fixt to the rope, or knots made by bending the chord it self, and cavities or hollowings of equal space from one another, to answer these knots in each pulley A B and C D; the pulley C D hath in its axis a little pulley E F made fast, from whence is suspended in the same plain manner the pulley G H; and so henceforward the pulleys may be continued as many as are needfull; from the lower pulley, viz. to the little pulley I K, of the pulley G H, hang the weight L, sufficient for the motion of the pullies, and of the perpendicular; all the axes of the hanging pullies must be moved not within a firm hole, but within a certain slit, or notch, cut from the top to the bottom, that while those perpetual chords and

the knots are contracted, or distended, the axes of the pullies may be raised, or depressed; the rest that belongs hereto, as the proportions of the pullies to each other, are easily understood from what is said before, all those pullies being agitated by the force of the weight L, will be moved circularly, and the perpendicular NP, freely moving in its centre or point of suspension, will be agitated by the little pulley A B, and the little rod A M: See the problem before cited, and the other ways of applying pendulums to Clocks before described.

According to the Author, the Pullies must be so disposed that their axes move within the slit, or notch, and that causes the Engin to work ill, for when the axes gravitate unequally from the other Pullies; or from the weight L hung to the Pullies, they are crooked or awry, and do not retain an horizontal site as they ought; wherefore the axes should rather be put into firm holes, and lest the chords be shrunk or stretched by wet, or drought, they may be wove of metallic threds, or wyres; but if you use common chords the axes must be put into slits, and not into holes, but the pulley ropes ought to be doubled, and the weight hung to the lower little pulley, to wit, to the axis of the pulley C D, another little pulley equal to E F must be fixt, and you must answer the same in the opposite face of the pulley; which little pulley in like manner with another perpetual chord must sustain the same pulley G H, or rather another altogether like it, and annex to it: Lastly, another small pulley like to I K must answer on the opposite face; then the weight L will be parted in the middle, and will be sustain'd partly by the little pulley I K, and partly by the other opposite.

Problem. XVI.

To render the motion of a Pendulum continual for many hours, or also whole days.

Many Artifices have been invented in the last years of this Age, and various ways thought on of rendring or effecting the motion of Pendulums continual, that they may persevere for many hours or days with the same perpetual velocity; from whence also this advantage follows, that all the vibrations are made in equal times; some of these kinds of Artifices

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Artifices I shall describe in this place, which seem to me most meet for the purpose, for any one of his own ingenuity may take occasion to think of others.

Fig. 146. First then, let the Pendulum be A B, to which at right Angles join the little arm A C, and let the upper wheel, or toothed Cylinder be D E, which being turn'd about draws with it another little arm D C, made fast in the base of its Cylinder near the circumference being round in the middle, and with a smooth pin, so that the little arm may be freely moved about this pin, and consequently while 'tis turn'd about the Cylinder, or wheel D, the little arm D C may be depress'd, or bore down, which conjoin in C with another little arm, and the angle C being enlarged will suddainly cause the lance of the Pendulum A B to be lifted up, which is join'd in A to the wood I L from whence being suspended 'tis detain'd, but nevertheless it freely turns about the smooth pin A fastned to the wood; then some sufficient weight being added to the lower wheel G, from this motion follows the motion of the wheel above it F, and this being in the middle (as it is wont to be in Clocks) turns about the uppermost wheel E D, which drawing with it the little arm of the pendulum, the same imprints a motion to the pendulum, as long as there is new rope which sustains the weight annex to the wheel beneath, or lowest wheel.

Note, instead of the Cylinder, or little wheel D E, you may fit a toothed Cylinder having a crooked handle, which will lay hold on, and turn about the little arm D C, such as is the Cylinder M.

Note also, by how much lesser the proportion of the diameter of the little wheel D shall be to the arm A C, so much lesser will the arches be that are described by the motion of the pendulum A B.

Fig. 147. In the second place let the pendulum A B be movably fixt in A, in its lance fasten the arm M G, which may easily run sometimes into this, sometimes into that part, and sustain it parallel to the horizon; from the middle part of the same arm M G stretch out wood or iron like a little fork, or two teeth, made hollow, sticking out as at L, which in its cavity or cleft admits the pulley E F, immovable and in an oblique site put into the axis C D; let this kind of axis be furnished with a toothed Cylinder, which will be turn'd about by the

the wheel N, by means of the weight P being added to it, or by means of other wheels, as you please : The Engin being disposed in this manner, while the axis I H is turn'd about of the lower wheel ; in like manner the middle axis C D is turn'd about by the toothed Cylinder, and with it the little pulley E F, which since it obtains an oblique site, it causes the arm G M, into which it is put to run to and fro, and moves the pendulum A B.

Fig. 148. Thirdly, Suppose the pendulum D B, hanging from the arm A C, immovably fixt in C, and let the lance of the pendulum be stretcht out somewhat above the point A, from whence 'tis suspended, to wit, in D ; then fit the axis E F, sustain'd in the middle by the arm F, to which join the toothed Cylinder L, and let this axis be stretched out through the hole of the arm F towards A. Lastly, in the extream part of it near A, let it be furnisht with a concave Cylinder, and being cut oblique, so that the section G D make an Elliptic figure ; the Point A from whence the lance of the pendulum is suspended, must be in the same horizontal right line with the axis E F, and with the arm A C ; moreover it ought to be precisely in the centre of the same section G D, although because of the cavity of the Cylinder the point of hanging remains free in the air.

Then while the toothed Cylinder L is turn'd round together with the axis E F, the Cylinder D G is turn'd all under one, whose extream or end being an oblique Section, hitting against the lance of the Pendulum it unites a motion like to the precedent.

Fig. 149. Fourthly, let the Pendulum be A B, whose axis A C carries with it two toothed Cylinders D and E, which in like manner here and there, lay hold on the toothed wheel D E, but with interrupted teeth, so that while one Cylinder lays hold on the wheel on one part, the other Cylinder lyes upon the opposite part of the wheel which wants teeth, and therefore the whole wheel ought to be divided into many rows of teeth in an odd number, and 'tis convenient to make each row of three teeth, and between one and the other row, a space of teeth left vacant, as much as is occupied by three teeth ; so as often as the weight shall be hung to the lower wheel H K, this being turn'd about, will move the toothed Cylinder F, which being in the middle, will move the fore-
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saïd toothed wheel, which biting the toothed Cylinders D, E, one after another, somtimes on one, somtimes on the other opposit part, will move in like manner the pendulum A B alternately.

And as in the foresaïd Engins, each vibration of the pendulum is made in a determin'd part of time; to wit, in one second minute, or in 20 third minute, &c. the proportion of the wheels and of their teeth must be observed, as in this last Engin, if we would compose each vibration of the pendulum to answer one second minute; in the wheel D E, dispose 25 rows of teeth with as many vacant spaces between, the Cylinder F must be furnisht with 8 teeth, the wheel H K must have 96 teeth, the Cylinder G likewise consists of 8 teeth, beneath which will be another wheel of 96 teeth, to which hang a weight; for in this manner 3600 compound vibrations will be made in each hour, each whereof will be equal to one second minute; then make fit the weight hung to the lowermost wheel, with the length and weight of the pendulum A B, in such manner, that the lower wheel be once turn'd about in an hour precisely, for so it will come to pass that the Cylinder G will be turned 12 turns, and the Cylinder F, together with the wheel D E 144 turns, and at last the pendulum will finish 3600 compound vibrations.

Instead of the wheel D E of discontinued teeth, you may use a toothed wheel common to Clocks, if instead of the Cylinder of teeth, laying hold on it, you use two little handles, which by turns shall urge and move forward those teeth of the wheel, by laying hold of them.

Inventions of this kind are excellent, not only in being serviceable in continuing the motion of the pendulum, but also in making of Clocks most exact as is obvious to every considerate person; which Engins or Clocks have this utility and conveniency, that they scarce make any noise in their motion, since the pendulum is instead of a Ballance, which in common Clocks cannot agitate without noise.

Problem. XVII.

To make a Clock to shew the hours on both sides, after a new method, which by a weight hung to either of its sides prosecutes its course, and the index of the Clock proceeds forward in both motions consequently.

THE Author before cited teaches this Artifice: See the last Figure of the preceeding Problem, where we have taught the method of continuing the vibrations of a Pendulum; for if you rightly understand the construction of the Artifice of this Engin, 'tis manifest from thence, that if, while the perpendicular A B is agitated, the wheel K H suddenly changes its turning about to the opposite part, that is, it begins to move to the right hand, when before it moved to the left hand, the motion nevertheless of the perpendicular will in no wise be hindered; because that in whatsoever place of its arch, the perpendicular A B lays hold on unawares from its first acquired *impetus*, it will continue the same vibration; but for the following vibration, it will have the favoring impulse to it self, for as much as the parity of the rest is the motion instituted by the wheels in this, or that part.

The same may be obtained other ways, as is explained in the foregoing Problem, but chiefly by the *Figures* 146 and 148, but yet easier by application of a Pendulum, which we have taught at Problem 5; it only remains then that an index be applied so, that although the turning of the wheels be made on the opposite part, yet it always proceeds forward in the same part.

Fig. 150. Let the axis A B be continually movable together, with the toothed Tympane B, firmly adhearing to the axis, which forces the wheels of the Clock on both sides to this, or that part.

In the first place, fix on the same axis, two wheels with fingers, or claws, within which smooth holes being bored in the centre, and the axis being smooth will move freely; moreover put upon the axis two other Cylindrics G H, and I K, with saw-like teeth or jags, each whereof must be firmly put into the axis, and turnable together with it, the jags of these wheels bend to the opposite parts, and are stified in the opposite parts by wedges, or little pestles C G, E I, each of which is furnisht with
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a little pressing wing in pressing its power, that the pins bending forward to the Jags, admit the motion without much resistance, and these pins are conveyed by the finger'd wheels C D, and E F, to which are fixt smooth little pins holding them at liberty; lastly, to the two finger'd wheels, there must be added a third C E movable with the axis L M, and its fingers folding in both the fingers of the wheels C D and E F, it may be expedient that the wheel C E refers to another site, to wit, vertical, (if necessity require it) the circle of the wheel being put in points designed.

Therefore the Tympane B with the axis and jag wheels G H, I K fixt in it, are turn'd in either part, for presently either of the jag wheels will be bound by its bar or pin, and render its finger as it were continual, which with the axis leads it with it self, and the wheel C E together; and because this infolds its fingers with the other wheels, it impells it but in the opposit part, in which its bar or pestle hinders not, in as much as the opposit jags, holding the former and admitting the motion on that part; now if the Tympane B change its turning to the opposit, then that which was first hindred by the pestle or bar will be loos'd, but that which was loose lays hold on his jagged wheel, which then first begins to move in the same part, in which his finger'd wheel moved before, and since the finger'd motion is the same now as before, because continued in the same part, therefore the motion will be continued, and the half of the Fingers C E; to which therefore an hour index being fitted, will always move forward into the same part whithersoever the Tympane B with the whole Dial is carried.

Note, First, That the wheel C E advancing always in this or that part, depends on the jags or saw-like teeth, reciprocally inclining, and turning towards this, or that part, whence if the site of both of them be changed by inverting both the jag wheels, and the other face being applyed to its finger'd wheel (the pestles or bars of the Jags, being also changed) the motion of the wheel C E will be likewise changed.

Secondly, if the wheel C E be led about by the hand in that part in which it was first impelled by the fingers C D, and E F, both those fingers will be moved, but the axis with the saw-like teeth wheel, resteth by force of this Construction if nothing else hinders, and may in the interim be turned in this or that part, while 'tis not moved sooner than the axis L M.

Thirdly, but if you will lead about the wheel C E by the hand in the opposite part, and not in it which it was decreed to move, no motion at all will follow, but the whole system will be firm, and will stick, so that the resistance of the hand detaining the wheel exceedeth, 'tis necessary to apply a proportionate power to the tympane B on each part of it, which is no less a Paradox than the former; this construction extends it self to many other Problems of motion, as the deducing the librating motion into Circular, to the recalling whatsoever irregular motion to a well order'd Circular, &c. as will appear in what follows.

Problem. XVIII.

The Hydraulic Clock of Father Bettinus.

THis kind of Clock is indeed very ingenious, and the invention of Father *Bettinus*, and afterwards increast and enlarged in many things by Father *Eschinardus*, of whose work also I have often observed not without great pleasure of mind, the like Engin made in the *Roman* College, which performed the effect best of any: Therefore lest our work should want somewhat of those things which scent most of Ingenuity, we have translated this from *Bettinus*.

The outward Artifice of the Hour Tympane.

Fig. 15 n. You see the express form of the Tympane conveyed from the axis through the centre, whose apparent Pole is H, and the other pole not apparent, and of the chord I K L M N P, whose two ends are fixt in I, and the little pulley K (if you please of Brass) with a small weight stretching out the rope lightly, that beyond L it adheres about the occult pole: But the great weight under the pulley N while the rope endeavours to draw the chafed axis, and as it were toothed, afterwards moves the Tympane together with the Tympane and the number 4 ascends, and after the Tympane movable pieces either of wood or iron toothed, whose form and art we will shew hereafter, and some such you see Q, R, while they hit against the movable and changing plate of metall S, it connects the handles T V X, being drawn together they raise the little hammer on the side of the little Bell Y to strike the hours.

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The art of changing the numbers in the hole, where 4, as it were, lies hid under the circular plane, as also the art of setting at liberty the teeth under the plane of the opposite Tympane, we will shew hereafter.

Sect. II.

The inward artifice of the Tympane.

Fig. 152. **O**ne of the circular planes being drawn aside the Tympane immediately shuts, and that on the other part opens, as you see in the figure annext; behold there appears to you the superficies of two concentric cylinders ABC, DEF within the Tympane, within the concave of the lesser the stays or props are G, H, in whose holes the axis of the Tympane is put, within the convex of the lesser, and the concave of the greater is the plane K, which is join'd to the cylindric superficies, and to the circular planes shutting the Tympane; through the little hole I of the small plane IK passes water to run, when the Engin is moved by force of the weight, and descending in C, the water is prest by the plane KI.

Therefore while the rope about the little toothed wheel, after H by the force of the weight weighing down to the parts beholding the left hand as FE, thrust through G, H turns the axis together with the Engin, and the plane KI descends and hits against the water, and presses it towards the parts beholding the right hand as MA; in the mean while the water trickles down through the hole, and by little and little the plane KI intercepts the middle between the water, until the water running between more and more through the hole I, and the plane KI ascending to the parts towards AD (or beholding the right hand) most part of the water which flows beneath the plane increases the force of the weight hanging about the axis H, and causeth the plane KI which now is idle in the parts AD with a little water (which it hath not as yet deeply flowing above it self) at length 'tis turn'd by AD with a swifter motion towards C (or to the parts beholding the left hand) and from thence it descends again and the water presteth, which again flows through the hole, &c. and so perpetually by turns the Engin is turned, the Orb compleating a rotation once in each hour.

The art is, that the dropping of the water continue an whole hour, whiles that after a slow and insensible motion of the Engin for an hour, unexpectedly the Engin turns, in the beginning of the dropping; in which revolution the hour is struck on the back part of the Tympane, but in the forepart the note or figure shewing the hour on the dial plate is changed.

Sect. III.

An easy and most ingenious Art, whereby the number of hours are always changed, and also the hours are struck in the Hour Tympane without the artifice of other vulgar movers.

Fig. 153. **T**HE invention of which, striking and changing, you shall have here in a double figure: And first, that which belongs to the changing of the numbers shewing the hours; suppose on the fore part of the shut Tympane, the plane to be drawn aside with the inclosed little boards.

The circle A B C D exposes to the eye that plane on the fore part, to which is affixt in E and F the Hexagon plane, lessened in on side P Q a half part of one of the other sides; and that Exagon is the excentric to the circle A B C D, having a hole G common with the circle (which is the centre of the circle) in which the axis of the Tympane is conveyed through. The hole under A is that, under which the number of the hour Indexes appear on the other part in the little boards, which must be noted in the hinder part of the little boards, but in the figure for plainness they are noted in the face apparent to the eye; you see those little boards joined to little thin plates of mettall with corners, the ends whereof are movable about the fixt little pins within the little boards.

The outward form of the art you have in the seperate H, and at I and K; imagine then the little board H to be in his place between I K, and to stand upon the side P Q, which is only fit to receive one little board, the other sides being large enough for two, as you see in the Figure; then while H between I K shews the number (which you must conceive on the other part) of the first hour through the hole A, and the circle A B C D is turned with the Tympane slowly, suppose towards A, the little boards 7, 8 fit themselves to the side M L, and 6, 5, to the side L R, 4, 3, to the side R Q, and by reason of the obliquity,

the little place succeed 12 fit the M N; 9 and the place of hang down beneath M I derful art th ther they sh under an op Fig. 154 hours is the plane boards, the sented by n al plane ex hole (which the Tympan gular with struck) ha gon, and a mettal mov done in the circle.

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ty; the little board H being removed from the side P Q, in its place succeeds 2, and shews it self under a form. Moreover H and 12 fit themselves to the side P N, 11 and 10, to the side M N; 9 and 8, hang down beneath L M, and 8 succeeds in the place of the middle 7 hanging down, &c. and three always hang down without, and beneath one side as you see 6, 7, 8, beneath M L; and by this ingenious, easy, simple, and wonderful art the little boards change by turns, and one after another they shew the hours, the number of hours being inscribed under an open bright hole.

Fig. 154. But that which belongs to the striking of the hours is thus; suppose on the back part of the shut Tympane, the plane being drawn aside with the inclosed toothed little boards, that plane on the inner part exposed to the eye is represented by the circle S T, to which is affixt in V X a pentagonal plane excentric in the circle S T, having a common square hole (which is the centre of the circle) in which the axis of the Tympane is put through; there are 6 little boards quadrangular with teeth (according to the number of hours to be struck) having bases somewhat less than the sides of the Pentagon, and they are made fast by the corners with thin plates of mettall movable about the ends as you see in the Figure, and as is done in the little boards of the hour indices in the antecedent circle.

That you may understand the form and art the better, you have set a part Z, suppose the thin plate (by whose impulse the little hammer is led to strike the hours) to be in *a*, and the circle in the Tympane to be turn'd from S towards *a* T, the little board B with 6 teeth or claws striking against in *a*, sounds six tinklings on the bell for the hours, and presently falls down beneath *a*; then B being oblique to the parts T, the little board *d* fits it self to the side *e*, and so of the rest in the Orb, as is said before of the little boards of the hour Indexes.

And it must be noted and effected, that the little boards with teeth of the circle S T, so agree with the little boards of the Circle B D of the antecedent figure, that they strike the hour, which is presently shown under the hole, the number of the little board in the circle B D being changed.

Also you must take care that the hour plate inscribed in the first Figure, *Section the First*, be diametrically opposit. to the plane K I of the figure in *Section the second*, through the hole

of whose plane the water trickles down ; and let the same hour plate be opposite to the little toothed board striking the hour (not shew'd in the plate) of the next following number, so that when the shining hour eye is below the Horizon of the hours Diametrically opposit to the little Bell, and in that eye they number of the hour is changed, in the same moment the toothed little board strikes the hour, which being changed the hour immediately appears above the Horizon.

About the hole I, in the plane K I, through which the water flows on both parts above and beneath the plane K I, in the back convex of the Engin are two broad holes, through which the water is poured into the Tympane, and when need requires is presently all taken out, and through the same holes appears the lesser hole I, in the plane K I, that it may be lookt after if any thing hinders the running of the water through that little hole, and those two greater holes on the back part of the Tympane, may easily be shut and open'd by two brass thin plates affixt with wax, or other fit glue.

And because in the beginning of the hours the Tympane is turn'd slower, afterwards always swifter, because of a lesser resistance of Water, therefore in one of the circular planes shutting the Tympane is put a thin plate of lead in manner of an hook, decreasing by little and little, &c.

Sect. IV.

Observations of Father Eschinard, to be practised in making the foresaid Engin.

THIS Author learned in Experiments advises in the first place, that the Tympane be divided in four equal parts by Parallelograms of thin plates of mettall, one whereof ought to be boared through with a small hole, as is said, but each of the rest are to be boared with a double hole much greater, one near the fascia, the other near the inward axis of the Tympane ; for hence it will come to pass, that after the water hath past through by the small hole in an hours time, then having obtain'd a freer passage, it permits the vessel to be turn'd about with a swifter motion, that in the interim the hour may be shown by a sign of the little Bell, or the next ellapst, or the next to come ; for unless the other thin plates are

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are made with greater holes, the Tympane will rather return than run forward; wherefore likewise an instrument may be made divers ways for striking the bell, to wit, by making it so that those points take up somewhat in their swifter motion after the manner of a Leaver, as is wont to be done in large Clocks with wheels, one end of which Leaver while it falls down draws the thred to it self, and raises the hammer; also sharp points fixt to the tables may be so fastned to the hinder superficies of the tables, that they may directly behold the Tympane, as also the centre of the Pentagon may be otherwise taken, &c.

Secondly, The iron plates being washt over with tin, corrupt presently, unless it be fenced by some Sandarac, or varnish, fit for the business; Copper cover'd over with tin, or tin only of it self, so that it be very thin, is best of all.

Thirdly, Beware lest the place of the small hole be so, that after some time the magnitude of the hole be changed.

Fourthly, The Tympane must be $\frac{3}{4}$ of one Palm at least, both in length and breadth, for if it be less it will not succeed so well.

Fifthly, The most fit water he takes to be rain water distill'd, but if the vessel be made of glass, hot water will be better; and the quantity of water ought not to fill much less than half the Tympane, but especially it ought not to come to the inner axis, wherefore that axis will be the better, if it be made as small as possible; the other things to be compared with one another are, the littleness of the hole, the quantity of water, and the force of weight; but chiefly you ought to take care lest that hole be stoppt, which ought to be at least as big as one arch.

Sixthly, He denies that the thing may be done with Quick-silver instead of water, both because it requires a greater hole to flow out at, and therefore also a greater Tympane, as also because it will pass out most heavily; lastly, because all mettall corrodes, and therefore the Tympane ought to be glass, which will be difficult to be made: Also he denies dust, or sand, to be fit for that service, since it ought to pass through a small hole by being compress'd in the middle, which is done by those thin plates of mettall, which cannot be obtain'd by dust: He concludes, if any Liquor be found in which heat and cold doth not govern, that is most fit, so it doth not corrupt the matter of the Tympane.

Seventhly, He asserts another such like Engin of his own composing, wherein he hath made a perfect Hexagon in the axis for the Pentagon, and about it seven Tables are gathered together in the same manner as above, every one of which bears before it one of the seven Planets described with its proper Character. Lastly, in the foremost face appears a circular thin plate of mettall, but that for one circular hole it hath six, each being described upon with some celestial Sign, beginning, *viz.* from *Aries*; then while the axis is turn'd about the Planets are moved to the West, but so, that in every circumvolution they go back to another Sign placed after it in due order.

Eighthly, He teaches in what manner one Tympane, so it be large, may suffice for striking the quarters of hours; says he, make a Vessel, which divide in 4 parts by 4 thin plates, and then divide it again, but in a contrary manner, that is, let it be cut by the plates in the Section which makes a circle, and take away, as it were, $\frac{1}{3}$ part of the vessel, whence there will be, as it were, two Vessels in the manner of one, then either of these will be divided in 4 parts; the plates which divide the lesser Vessel ought all to be double in a place, to wit, nigh the fascia, and nigh the axis, to be opened with large holes, and the plates of the greater vessel are boarded double in a place, but with an unlike hole, to wit, one nigh the Fascia very small, and the other the axis much greater; for this is necessary to communicate the air to every part of the Vessel, otherwise the water will not pass freely through the small hole; lastly, put the water in so to the lesser vessel that it may almost touch the axis, but in the greater vessel as little as may; be for hence it comes to pass, that when all the water in the greater Vessel shall pass through the first small hole, before that (since 'tis but little) the impediment of the second thin plates hinders, in the mean while the Clock will be moved swifter, but because this way it rather returns than goes forward, therefore 'tis restrained by the water put in the lesser Vessel, which in the interim passes through the great hole; then while the Clock in this manner is moved, after every quarter of an hour it strikes on the little Bells the number of quarters elapst.

Note this one thing diligently, *viz.* lest that slow motion be too short, as not to suffice for the striking of the Bells as often

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as is required; also note, that hence it necessarily happens, that the outer face of the Clock is a little changed; for otherwise it will follow, that in the middle of the second hour, the number of the hour appears not longer, which evil we may easily cure many ways.

Hence he concludes, that this second division of the Tympane may also distinguish the Tympane for so many hours, for hence, says he, proceeds great benefit, for you may as you please make the motion more or less slower for striking the bell, *viz.* if you put more or less water into the lesser vessel, although you leave the greater vessel untoucht; but in this case 'tis sufficient, if the greater vessel only be divided with so many thin plates; for the other plates are put only to restrain the too slow motion, as is said before.

Ninthly, Because those things which are said seem not fit to the striking of greater Bells, three vessels are to be made in this manner: Two of them must be divided into 4 parts in the main, as is said of the lesser vessel for the quarter hours, the third must be also divided into 4 parts, but the same altogether after the manner of the greater vessel for the quarters; the water in the first two vessels is put in as you please, but the same must be observed as in the lesser vessel for the Quarters; and in the third you must observe that which we have said of the greater vessel for the quarters: But now if to the end of every quarter the third vessel (as is usual in great clocks) lift up somewhat, so that it being raised a free course is permitted to the other vessels, to wit, to one of those in the end of the hour for striking the hours, and the other to every quarter for striking the quarters, the thing will be accomplished.

Tenthly, The foresaid Clock hath this peculiar, that it makes no noise, nor the motion of the Ballance, nor the Wheels disturbs not nocturnal rest: Notwithstanding if you would make use of it to rouse you from sleep at an appointed time, you may easily do it, by taking all the teeth from the Tables, except one of them, which you must fix in such place and order, that after the prefixt number of hours it may strike on the bell, or make some other noise, as is wont in excited Clocks, of which we shall speak hereafter: There are also other ways more easier, as if you use to it the percussion of a weight, whereby one part of the equilibrated table depresses a

Cliggut, something fallying out into the room, and you may encrease or diminish the percussio of the weight, by making a greater or lesser hole in the other three plates, which have large holes for the swifter motion, &c. But if you add one wheel, you will find several easy ways.

The Author concludes, that hence all those Engins may be supplied by a short Compendium, which are not wrought but by many Wheels, especially in those which want temperate motion.

Moreover he adds many other things to equip this Engin, and, *First*, he says, the vessel may be so accommodated in the outmost part, that at what time the Clock is moved swiftly, whether before or after the Strokes on the bell, little boards being placed, or such like, as is wont in Hydraulic Organs, it will utter a consort of musick, either in some Cimbale, or on little Bells harmonically disposed.

Secondly, If the Clock be hung after the usual manner to a wall, and to its side, some plane table be made fast to the wall through the length, that it be parallel to the horizon, upon that table may be placed the Sun in its course, a hidden string being drawn which tends rightly to the Clock, which may be drawn by the vessel in its circulation; and on the wall you may dispose in right order (in the way through which the Sun runs its course) the heavenly houses, whence each hour, a little Image poetically adorn'd appears, which shews the hour on the right hand next elapst of the Sun, and on the left hand it leads some of the heavenly Signs, or some sign of the *Zodiack* addicted to that house, &c. thus those little Images will appear every one to his time; put cross in the way by which the Sun passes, some little board, so that when the course of the Sun being moved by the swift motion of the Clock, being carried in its course, it hits against one end of the little board; which if the little board be placed in manner of a leaver, it may so be accommodated that while one of its ends is drawn, by the service of the other end with some string added to it, the little image is brought forth to the Sun, and there left.

Thirdly, Besides that heavenly motion, that number which shews the hour next elapst may be so accommodated, that the same site and face may serve, as well in its Apogee, as in its ascent and descent, to wit, if there be put to the little plate

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on one of its parts some tin, a little heavier, being so affixt to each table, that it may most easily be turned about its centre.

Fourthly, Almost in the same manner, in that circular superficies whose half part always appears divers small Images may be affixt, so that they always remain aright, by means of Tin, or some other heavy thing added to their feet, and in going forward they may shew the quarter hours, &c.

Hitherto we have added no Wheel, but if we add one or two, you will attain many fine effects. First, a toothed wheel may be so placed on the vessel, that its axis may fall right on it, and on the extream circumference of the vessel many iron stiles may be put, which while the vessel is turn'd about they move the overthwart wheel placed above, by hitting against its teeth, moreover you may constitute a Load-stone on part of the wheel placed above; now if you fasten an Image with a wyre, with an iron stile in it hands, according to the motion of the Load-stone, it will shew the hour, &c.

Problem. XIX.

To make the Indexes of Clocks, so that they shall describe not only Circular, but any other Figures by their motion.

IF any one would adorn the Index of a Clock with the Arms of some Prince, or City, to dispose it in the form of a shield, of a heart, of a cross, &c. so that the same being artificially made, or a small image, or any other sign performing the office of an Index, the numbers of the hours being inscribed on the parts of its figure, in whatsoever order they are disposed in, it will shew successively; or that an Eagle with its bill, or a Lion with its tongue, &c. There are divers Artificers in *Father Schottus Technica, Book 9. Chap. 5.* the most useful whereof we will here impart.

Fig. 155. To describe the most difficult figures of moving Indexes assume the artifice of a Parallelogram made in this manner: First, of solid matter, *viz.* of iron make four rules A H, A K, K L, H M, which in the points A, H, C, K, so join with curious small pins, that the square may freely be stretched wider, or contracted narrower; then to those portions or parts standing out on each side C L, C M, join by the same ar-

lifice as many more rules, but shorter, and if you will, decreasing in the same proportion, and in the connecting or joyning points, freely turning.

Secondly, On that face of the Index that lies hid towards the Clock, conceive a hidden toothed wheel CDEFG B, to wit, so as those Indexes that are wont commonly to turn once in 12 or 24 hours, in this being made hollow, or any other way fitted, understand a little Channel A C, so that within it a little nail, or pin C, may be put sticking out from the Parallelogram towards the Wheel, and may run to and again, this way and that way, without resistance.

Thirdly, Fix a small pin A in the Center of the toothed Wheel, and then between it and the other little pin C, which ought to run in the little channel or groove, a Spring, or some impulsing Spire, being put between by a Wyer of a competent thickness in the manner of a wreathed Cylinder screw, drawing aside as much as is requisit the little pin C, from the other fixt pin A; which Spire perhaps may more conveniently be made of a Serpentine plate drawn and bowed.

Fourthly, Propose now any figure which you would have the hour index describe with its point; suppose a Hexagon, or figure of six sides: Cut then in the plane of the Index a six sided hole CDEFG B, whose Center is A.

Fifthly, Upon the whole Parallelogram, and the hole that is cut, place some figure, as of an Eagle, or a Dragon, &c. so that its neck touch the texture of the Parallelogram and hide it, and the other part of the body be spread over to the hole that is cut; Moreover that Parallelogram being wove in the neck of the figure by more of the same Rules placed between, in the likeness of a net, and move artificially after the manner of feathers, or the Scales of a fish, &c.

The hour Wheel then intercepting the pin C in its groove, carries it a long with it; and this from the drawing pressing plate placed between A C, and the cut. Sexangular hole, or included between other limits, will cause the Eagle, having a crown, cross or star on its head, or a Dragon with his tongue or stinging, to describe the same figure, and to shew the hours described in its limb.

In the describing of other figures, as of a heart, a rose, a shield, &c. the Industrious will find it easy; another motion may easily be given over and above, to a Lyon, an Eagle, or a Dragon,

Dragon, &c. that this spread his Tail, that tofs its Spires, the other open its wings, &c. and that either by the same artifice, or otherwise.

Problem. XX.

To perform the same more Compendiously.

ALthough the foresaid Artifice is universal, and extends itself to many figures, yet this present Proposition may be reduced to practice, with less charge and trouble, especially to the easier; as Ellipses and Polygons, and moreover may be applied to other Paradoxical affections.

Fig. 156. Let A B C be a rod of mettall, having a round hole in A, but in C where it bends, it ends in a little ring, or other erect hole C E, through which passes another rod D E F, which bending in the like little ring F B, and in like manner made fast to the former rod, and close or touch each other so lightly, that they are carried on one within the other to and fro freely; in the end D is made an arrow, a little Star, or other such like shewing Apex.

Secondly, Understand in that plane in which the number of hours are inscribed some figure, *viz.* a Square to be described G H I K, and nigh to its designation cut a channel or groove of any depth, and its breadth, so that standing out from the little ring it may receive the point B, that it may run freely in its Channel.

Being placed then, and fixt to the hole A in the Centre of the quadrature, and to the style B in the same cavity; if this whole joining together of the Index in the point A be turn'd about by the Axis of some Wheel, or led about circularly any other way, the end D must needs describe a Square figure, or another after the same manner, as is the Channel in which the style B is led about.

Note, First, the same Instrument may be more ingeniously made of two rules, in one of which a little channel is drawn out in length, and the cursor runs to and fro in the other by turns; but the Artifice may be so cover'd, that the contraction and distension of the rules cannot easily be noted, in producing the rule D E F beyond the centre A, &c. *Secondly,* If between

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the rings E and F you put a wire, or a divided plate of mettall, it will not be necessary to hollow it in the plane, but only cut it out from the thicker plane being laid upon the other, or by the rules that frame the Poligon.

If you affect Paradoxes, hence you may easily deduce, *First*, that by the continual drawing and revolution of one and the same common compass, you may describe a triangle quadrate, &c. for if one foot of the Compass be fixt in the hole A, and the other firmly lay hold on the Style E sticking out, and being led about by the compass, the style will describe such another Figure D, and was the little hollowed Channel, or another supposed plane terminated by a certain figure.

Secondly, If you would describe a circle by the same opening of the compasses, and not from the Centre of the Circle, you may do it almost in the same manner, which doth not require that the point A with the foot of the Compass be in the middle of the figure, as is manifest.

Thirdly, you will increase the admiration, if you add the describing a Triangle, a Square, an Ellipses, &c. greater or lesser, with one opening of the Compasses, and you may effect it thus; Produce the length D E F towards A, and let the little ring or Cursor B F, have a screw, or turning joint in F, that the compasses remaining at the same distance, and only the relique D E F being drawn from, or intruded from all the rest, and the foresaid turning joint may be fastned in F: More may be added by the Ingenious.

Problem. XXI.

To make and incite a Chronometric Index to an Elliptic figure, by a certain and peculiar method.

ALthough both the foresaid Artifices serves to describe Ellipses, yet the Author adds another, taken from a peculiar Geometrical Instrument of *Guido-ubaldus*, or rather deduced from the same foundation.

Fig. 157. Three planes, or thin plates, are to be conceived, the first is of an indefinite figure, which is described by the Elliptic Index A B C D, this is boared through in the middle in the round hole H E F G, and moreover cut in with four slits

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at right angles which are I E, K F, L G, M H, and join'd together with a round hole, the length of the slits is as much as the Semidiameter of the hole.

The other Plate P L is circular, which hath on that part some Index which is laid open to the view of Spectators, being put upon the former slits, and therefore touches the foresaid hole of the former plate.

The third plane of the orb is I K L M, touching the same hole on the other part of the middle, and of the slits of the plate, and this therefore lies hid all within; its Centre is the same with the Centre of the round hole, and it hath Glued or Soldred to it, two Segments above and below the Centre, being cut through by a circle on its Periphery, that perfectly fills the sides of the hole, and razes while they turn within the hollow of it; the thickness of these Segments is the same as the slits of the plate, with which they are therefore equal and alike.

The conspicuous Orb P L hath its Centre in that point, which is posited in the Periphery of the Segment H E, Glued to the hidden orb M I K L; In this point a hole is made through each orb, to wit, the conspicuous P L, and the occult M I K L, to which hole afterwards a smooth little pin is put, to join each orb freely.

In the conspicuous orb P L on one face which beholds the middle, or slit plate, are fixt two little round nails I and N, of the same thickness as the breadth of the slits, within which they ought to run to and fro most freely; the length or height of the little nails or pins is the same as the thickness of the slits, and the plates, or somewhat lesser, lest they touch the occult orb through those slits, and raze it in the motion; they are distant from each other the interval I N, equal to the diameter of the hole.

In the inner and occult orb make the hole R somewhere, into which enter some little nail sticking out for that end in the diurnal Wheel of the Clock, whether it be turn'd once in 12 or 24 hours, the Centre of which Wheel ought exactly to answer to the centre N of the hole H E F G, and also of the occult orb I K L M; the distance of the hole R, and of the little Nail answering it, will be the same *viz.* R N; it is the same, if in the diurnal Wheel of the Clock a hole be bored through, and in the point R of the orb a little pin answering it be fixt.

The foresaid pin then being entred in the hole R, will cause the occult orb I K L M to move about, being laid hold on by

by the Wheel of the Clock, and will carry it forward from R towards M; and at the same time a hand being formed, a Lilly, the Sun, or such like, the Index P will proceed forward to the opposit part, and by its apex describe the Ellipsis ABCD, to which hours unequal spaces are described distinctly, which nevertheless are finisht in equal time, to wit, hourly, by the Index.

Since the conspicuous orb P L, on this face, on which 'tis beheld, is altogether plane and whole, you may for ornament inscribe on it, either the Effigies of the 7 Planets, or the figures of the 12 Signs, which indeed have no other use, than that they are turned about wonderfully to and fro with the orb, that he that is ignorant of the structure, and its make, can hardly conceive it, because that the orb is moved with a double motion, one by which its Centre E is carried circularly about to the Periphery of the hole E F G H, and the other Eliptic, whereby the other parts of the orb are carried.

The Internal F H between the two Segments is therefore left, that the little nails I and N may pass in a right motion through it diametrically opposit without obstruction from one slit to the other. See Guidubaldus in the *Demonstration of the Planisphere*, and Bettinus his *Comments on the 28th. Proposition of the 6th. Element of Euclid*.

Problem. XXII.

Divers ways to make a right lined Index to shew the hours, or quarters of hours, by a right motion, and then to return back again.

Fig. 158. **M**ake a plane Wheel ABCDEF, whose middle part DEFA is furnisht with teeth, but none in the other parts, the axis A G, H D lies directly over, or upon the Centre, or diameter of this Wheel, carrying two toothed Tympanes A and D, also two toothed Wheels G and H, which all firmly adhere to the axis A D: *Thirdly*, make the Oblong I K L M, three of its sides being of Solid mettall, and the fourth K M is closed by the figure of the Sun, or any other sign, moving forward by a right lined Index, which nevertheless may be placed most conveniently in the middle of the oblong;
Fourthly,

Fourthly, to the two longer sides IK and LM, make the teeth of the Wheels G and H to agree to the teeth of the other, *viz.* to the face of those sides which the Wheels G and H behold and touch, for that oblong is conceived to lie upon the Wheel G and H, and these to cover over the sides IK and LM.

The half toothed Wheel moving then in the first place from A towards B, will move the Axis AD, with the Tympanes and Wheels in the second motion, with which in like manner is carried on the oblong with the Sun KM from K towards B; and the length of the sides IK, LM of teeth ought to be in the same ratio to the Wheels G and H, as the Semiperiphery DEFA to the Tympane A or D equal to it; Secondly, and because the plain Wheel is furnished with teeth only in the middle part, which begins to impel the Tympane A First with its teeth, the Tympane D opposite to it is hindered by none, much less when the whole axis and Wheels are turned, and by an unanimous consent both wheels G and H the sides of the oblong, are so long forc'd forward by an uniform motion, as the channel'd Cylinder A is impelled; *Thirdly*, when first the toothed Semicircle approaches to the Tympane D, and begins to set its teeth in it, in the same moment the Tympane A is freed from the force of the teeth, and is turn'd to the opposite part, being led by the other; from whence also the oblong removes the track out of the way to the opposite part, as long as the toothed Semicircle forces, which it ought to perform 12 or 24 hours, or, if you please, but one hour: *Fourthly*, this whole artifice is hid beyond a certain table equal to the oblong of the Index, which therefore is divided into 12 equal parts, or hours, and the number of the hours are described in a double row, the uppermost of which from 1 to 12 shews the Astronomic hours from Midnight to Noon, and the lower from Noon to Midnight, or otherwise.

It may be done easier, for the weight in the space of time in its descent of the whole height, either in a plane vertically erected in some place, the same horary intervals may be designed; and the same perpendicular motion of the weights may easily be translated into an horizontal one, by a Pulley put between, on which put a small chord, and bind it to the descending weight; or if you find that inconvenient, fit a Pulley, or Cylinder, in some Wheel of the Clock, measuring time by its motion, for a Chord being folded to the Cylinder ac-

Cording to the various magnitude of the Pulley, or to the number of its revolutions made in an hour, will give divers horary intervals in the plane designed on the Wall, or other plane of a competent length, in which, if you please, you may hide the Artifice, and within or behind the table of the right lined Index you may place a piece of load stone from the weight by the foresaid little chord to move forward slowly being loose, and without the table, in the sight of every one, may be moved by the hidden load-stone an Iron gilt with the Sun, or *Phaeton* driving a rosey Chariot, a Chamelion, or a kind of Sea fish, &c.

Problem XXIII.

To Effect the same another way more ingenious than the former.

Fig. 159. **B**Ecause the foresaid Author appoints in the first practice, that the toothed oblong forcing the Index, and lying hid behind the table, while 'tis conveyed to and fro of its own accord, requires another space equal to the table to which it allows and extends it self: and in the latter way, whether he appoints it by finite or perpetual Chords, he doth it either by attraction of small Chords, or of the Index by a small chord, from whence 'tis moved forward, therefore I have thought on the following way whereby both those defects may be remedied.

Let therefore the whole length of the table of the right lined Index be AB , or CD ; take a chord, or small rope, six times the length of AB , and join the ends to make it perpetual, as $EABFDCE$; Put this about two Pullies, or Cylinders E and F , moving freely about their Centers, so that the small Chord pass occultly under the upper border, or limb of the table AB , and of the lower CD ; Secondly, let there be also some Index as G , so fitted that it may move forward to and fro through the whole length of the table freely, which may be done thus; it may run to and fro within two little Channels, or grooves, cut in the upper and lower limb of the table, or by two other metallic Chords, or wyers, strongly extended and hung in the same limbs, and it strains them lightly with its loose

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loose little holes, or rings, through which the chords are transmitted ; then the Index G will be moved forward in these channels, or wyers, perpetually by the little rope to and fro in this manner : Because the perpetual little chord is six times the length of A B, divide it into six parts, as A B, B F, F D, D C, C E, E A ; moreover in the three points of division A, F, C, omitting one interval, or space, bind or fasten just so many enforcing flexible obstacles with this condition, that passing by the perpetual small chord through the two loose rings of the Index G, *viz.* of the upper and lower, the obstacle hitting against the ring of the Index moves forward the Index ; and the Index arriving and consisting at the extream side A C or B D, the obstacle being drawn by the perpetual chord, nevertheless going forward passes through the little ring of the Index overcoming that small matter of resistance. To this end you must take small stalks cut off from the Quills of Birds, or Horse, or Swine's hair, or the strings of a wood-like White-thorn ; then these three obstacles being conveyed overthwart by the perpetual chord in the points A, F, C, and fixt ; conceive now one of the pullies E or F to be annext with some wheel of the Clock, as with the diurnal when you would have the Index to be of 12 or 24 hours, or with the hourly, or quarterly, &c. if the Index ought to be hourly, or of quarters : Let it be hourly, and either of the pullies E or F to move regularly circular by the hour wheel of the Clock from whence it will be incited, or by another perpetual chord, or by a toothed Wheel, &c. And make the motion of the Pulley, and of the perpetual small Chord, furnisht with the obstacles, or small strings, or hairs, the upper from B to A, and the lower from C to D. Understand now the Index G, to be brought by the horse hair, or other string A, from B D to A C ; Then because the Index cannot pass further, the horse hair notwithstanding being drawn by the perpetual chord, it will pass through the ring of the Index, which it will lay hold on, and will pass forwards towards E. At the same time the hair or string C applies to the lower ring of the Index, and the Index being free from the former hair A, draws it back with it self from C towards D, then the Index hitting against B D the Margent of the table, this lower hair will pass through its ring, in the mean while the other hair F is now found above, which Index that it may remove it forces away, and this reciprocation

of the Index endures as long as the motion of the Clock, if you diligently observe what follows.

First, Observe the Compendium in the beginning of this Problem; for whatsoever is without the table A B C D of the Index, you will contract to a less space, if you wind about the Pullies E and F once or twice those portions A E C, and B F D of the perpetual chord; for in this manner those Cylinders, or Pullies, must needs be moved near to the table of the Index, and always to its top, as the Centers of the Pullies E and F answer to the extream limbs of the table A C and B D.

Secondly, to continue that reciprocation of the Index without any error, you must take great care that the precedent obstacle, or hair, pass through its first ring, and leave it before the succeeding one sieze his, which you may easily obtain if you do not permit the Index to come to the extream terms A C and B D, but a little before it touches them, 'tis forc'd to stand still, and is freed from the former mover, that the other coming too, which was first dispatcht by the former obstacle, may find out the Index, which will be done in a short time.

Thirdly, Because at the first aspect of this Index you cannot know whether it goes forward or backward, therefore the thing may be so ordered, that one Index in going may turn to the spectators a face of one colour, and the other in returning a colour contrary to the former. If yet the number of hours or quarters above, be gone forward from A to B, and the lower from B C, it will be known presently at the first aspect, whether the Index goes forward or backward.

Problem XXIV.

To make the same power which moves the hour Index to strike the hours also.

FAther Schottus thinks it may be done by a spring, or steel spire; for since each spire after this manner hath two ends, central and circumferential, one of which being drawn, each returns to the opposit parts; says he, one end, *viz.* the Central, may force the Wheels of the Index, and the other the striking Wheels, or the contrary; And he affirms that the irregular force

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force and resistance of the spire may be made fit by the artifice delivered by us before, notwithstanding this must be diligently observed, that some certain time must be appointed by the Artificer, wherein the Clock is to be drawn up, and then according to the number of Pulses of each hour the other loose end will be made fit, the Cone of this other end forcing the chronometric Wheels; But in this practice some difficulties occur, wherefore I esteem the following practises of the same Author more apt.

Fig. 124. First, therefore conceive in the Figures of Probl. 2d, the two Pullies A and B, to be fitted to the two whirling systems of the lower Wheels, that is, to their axes; one indeed to the Chronometric systems, or circumagent Index, and the other to the strokes designed; for 'tis manifest from the right understanding of hanging of weights, that one and the same weight D serves both for the carrying about the Index continually, and to the striking of the hour Wheels.

Note, First, the Pullies A and B in *Fig. 124.* must be understood to be so placed as you see them designed in *Fig. 125.* *Note,* Secondly, if you do not make use of a perpetual chord, but a finite, then you must conceive that Chord to be perpetually dissected, and to each end a weight, or poyser, to be hung to continue the Chord within the Pullies A and B. *Note,* Thirdly, both ways here requires this weight D to be as heavy again, as that which is sufficient to carry about the other Wheels all at once: If therefore to each single weight that motion should be effected, you may make use of this following (although more laborious) practice.

Fig. 160. Secondly, make the Axis A B strong, and like a tree, or Cylindric, and stablisht in the points A and B, put on to this two toothed Wheels C D and E F, each of which shall have in its Centre a Cylindric Tube A G and B H, join'd or fastned together moving freely about their Axis A B: And to the ends of these Tubes G and H, must be fastned a little orb, or Jagged Wheel G and H, having but few jags, or teeth, as 12 or 16, but very deep; Thirdly, to the same Axis A B between each Wheel in the middle place, put the Pulley K I made hollow for receiving the Rope, to which that one only weight must be bound, and this Pulley also must be movable about the unmoved Axis.

Axis A B; and in the Bases or Planes which behold each Wheel, must be Bolts or Bars, on both sides the same number, and made by the same Artifice on both sides; *Fourthly*, the Bar therefore M L, whereby the Pullies are joyn'd together, hath first of all a hole, through which and the ear or ring made fast in the Pulley, passes the little round Axis, moving freely in the joints forsaking that Bar: The same Rail or Bar towards the Axis of the Pulley, holds out a certain hook, or little arm, athwart, as in Leavers full of corners or nooks; and lastly, towards the other end L 'tis bent like a hook, or bill. *Fifthly*, the Rails or Bars being fitted in this manner in the ambit of the Pulley in any number, as 3 or 4, so that all together they answer the Jags of the Wheels G and H, understand between the Jagged little Wheel G, and the Pulley I K, some Lilly, or like flower to be put, cut out of a thin plate of mettall, whose little Leavers sticking out towards the Centre of the Pulley, press the points or little arms of the Bars or Rails, that in this manner the bars L M, strive or strain always against the cuts of the Jagged Wheel, and the same is done by the face of the other Pullies. *Sixthly*, to the Tubes, or hollowed Axes of the toothed Wheels, must be put some Cylicindric Segments N and Q, upon the foresaid Axes or Tubes, movable freely to and fro; and join them to some firm Beam N O P Q, that according to the motion of one Cylicindric Segment, the other may be moved with a reciprocal motion. *Seventhly*, make some ballance C K E, movable in the Centre K, about which the half toothed Wheel is conveyed with it, whose teeth answer to the slits or cuts of the Beam O P; A little arm is erected in the upper part of the same Ballance answering the little tongue, or cock, of common ballances, to this is affixt the Sphære R of a competent weight. *Eighthly*, to the Tube or hollowed Axis of the Wheel C D, is put the little orb A, or smooth Wheel, movable together with the former, nevertheless it hath in some certain place of its Periphery one triangular tooth erected of unequal sides, and of such form as you see in Wheels, with Jagged, or saw-like teeth, so that it's *Hypothenuse* rises up slenderly from the ambit, or Periphery, and at length is ended in the precipice of the *Cathetus*, this little tooth about the end of any hour, lifts up slowly the little arm C, then when the ballance C K E is inclined it pulls up the little orb A.

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These things thus prepared, understand *First*, the Horometric System to be the superstructure of the toothed wheel C D, and the system serving to excite the strokes is of the other wheel E F; moreover from the pulley K I is hung some competent weight by the Artifices proposed before in Problem the 2d.

Secondly, Understand the ballance C K E with the weight R to be inclined towards the chronometric Wheel C D, for so it will come to pass, that the Wheel half toothed K forces the Beam O P towards the same toothed Wheel C D, and together with the Beam, each Cylinder N and Q.

Thirdly, One of the hour Cylinders, *viz.* N, when in this manner it goes back from the jagged Wheel G, it thrusts down all those hooked rails or bars in its incisions; and by the contrary reason the Cylinder Q being moved to the jagged Wheel H, lifts up all the rails or bars on that part, so that the jags in the little Wheel H are in no wise laid hold on by them.

Fourthly, When in this manner the weight hung from the common pulley hath a connection with the Wheel C D, and none with the other Wheel E F, that Wheel only will incite, and not this, and that will be done in an hours space, until the tooth sticking out in the little orb A, begins to take up slowly the little arm C, and with it the whole ballance C E, and also the weight R.

Fifthly, The weight R being inclined beyond the line K R towards P, suddenly rushes to the opposite part with the cock of the Ballance, and together with the half toothed Wheel K, impels the Beam O P, and the Cylinders N and Q towards B; wherefore the Cylinder N lifts its hooked Bar, and the Cylinder Q lets it down, and this being received within the jags of the Wheel H, make firm the Pulley K I with the Wheel E F, and its Wheels pertaining to the striking, which unlocks the arm K E, by a certain Leaver which the Figure doth not express.

Sixthly, The hour being declared by striking, the ballance C E is again lifted up with the weight R, to the opposite part by inclining towards O, and that is done by the *Phonotactic* Wheels, especially by those which are thrust on immediately from the Wheel E F, and which for every blow or stroke is

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wont to go once round, and carries in it's Axis a certain heart, by help whereof through Leavers disposed to that purpose, it may be done very easily, the Imperus of the Wheels approaching from the collected motion.

Note, *First*, in stead of the Pulley K I, a toothed Tympane may be placed, which may be moved by another inferior Wheel, and it's weight, for the same effect will follow, by increasing the weight of the clock as much as the thing requires: Notwithstanding the forces of which may be hindred by a spring, or steel spire, but only in a fixt, or standing clock, for in a portable one the same foundation remaining of shutting by the bar LM, the other furniture of the Leavers will be otherwise disposed to work changes. *Secondly*, when the *Phonotactic* Wheels are incited by the weight, the motion of the Index ceases the same time, but after that manner that either 'tis of it self but little, or 'tis compensated from elsewhere; also it may be so made that between those strickings, the Index shall not move forward at all, but the more free description of the artifice, the brevity of time excludes. *Thirdly*, if the *Chronometric* Wheels are incited not by a ballance, but by a Pendulum, the Artifice may be effected easily, that that may be apprehended and included in the uttermost term of its arches, and then the weight being restored to its Wheels, 'tis unloosed into Vibrations, otherwise the motion of the Pendulum once ceasing, it cannot be stir'd up again by the weight only; the rest I leave to the Ingenious to consider. Thus he.

And truly this practice is very ingenious.

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Book IX.

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Fig. 161.

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Problem XXV.

To cause any strong blow or stroke usually struck on great Bells, by a Hammer, and by great Weights, to be effected by much lesser weight, and fewer toothed Wheels.

Fig. 161. **L** Et the Wheel ABCDEF be divided into 6, 8, or more parts, in the division of which points make so many joints for certain equal arms and equiponderant hammers, or Iron balls, or Globes, to be fixed, yet so, that the motion of any arm run not out beyond the quadrant of a circle, *viz.* DGH: To the Axis of this Wheel place a Pulley with a weight and one toothed wheel, which shall turn about a certain axis with a ballance, to retard the motion of the whole Engin, and also the impetus caused by this ballance, &c.

Rails or Bars then being advanced shutting up the motion of the Engin, after which some hammer, to wit, DG must be conveyed perpendicular to an Horizontal site, and a little beyond the hammer falls down with a force, and describes by its fall the arch GH, and on the brim of the objected Bell strikes a stroke, or blow, and because it touches only the extream of the Bell, 'tis presently withdrawn by the Engin from proceeding any further, otherwise if the hammer should rest a little while, it would hinder the sound of the Bell, some steel plate should be put between by the side, which should draw the Hammer immediately from the bell, and not hinder it from tending downwards: And in this manner, much lesser weight being disposed, forces the Hammer and makes the strokes more valid, because the Engin is as it were Æquilibrated: The same may be performed by Iron Spheres, or Globes, falling from on high on the bell, which Globe is again raised to the height by a screw with a small power. Or so many Globes may be placed in an upper place, as are required for all the striking of hours for the whole day, as also of each hour, *First*, one of them is freed from the obstacle that it may fall on the Bell, afterwards two, and after that three, &c. according as the number of hours require: The hours may be adorn'd with divers other new ways to shew the distance of hours, for 1st,

if you would shew not only the hours, but also the quarters, you may do it by many small bells, to wit, make use of five little bells, whose sounds ascends by degrees in a Musical increase or proportion; and for the stroke of the first quarter, the meanest or lowest little Bell will sound Do, or, ut; for the second quarter Do, re; for the third Do, re, mi, then follows the stroke of the hour sol, sol, sol, &c. so often as the present hour requires.

Secondly, the same may be effected by means of musical Chords, to wit, if you extend them on a table made thin and hollow, either Parallel to each other, or as radius's meeting in one point; and they may be so fitted and tempered that two opposits give a Harmony, beginning from perfect and proceeding to imperfect, for these kinds of Harmony being incited, each hour by a diurnal Wheel with two chords, will signify the hour decreed in a bed chamber, which may be heard in a night without the trouble of noise; and the Impulse of the chords may be repeated three or four times, lest the hearing be deceived, if you have a musical Instrument with keys, you may use a Phonotactic Cylinder direct to the Clock, with a weight hung to it, by which it will be turn'd about.

Thirdly, the thing may be effected likewise by the Pipes of Organs, for if the Phonotactic Cylinder be made and applied to the keys of the Organ, and the Bellows being drawn either artificially by some easy Engin, or being once drawn persists so, and they must descend by little and little each hour while the sound of hours is required to be made.

Fourthly, the Strokes of the hours may be made by a military Tympane, or drum, and that most easily, as to any Industrious person will appear; yea, we affirm it is not difficult by Engins to exhibit to the ears, any strokes or blows wont to be declared by Tympanes, with as much dexterity, as it can be done by the most skilful Musick Master, both as to the Celerity of the blows and the difference of inequality of Percussion, and also as to Harmony or the sounds of Tympanes in Musical consort. *Lastly*, there is no Musical Instrument, the Tube or Trumper perhaps excepted, but it may be so fitted to a clock, as to make divers Harmonical sounds each hour.

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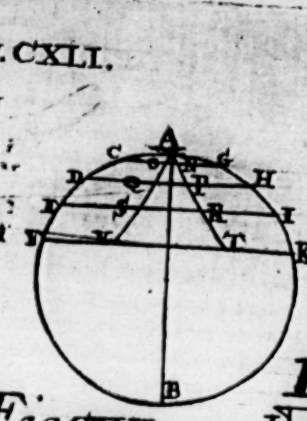


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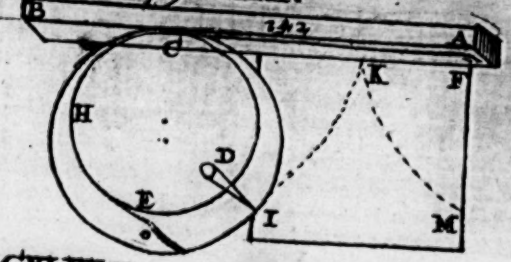


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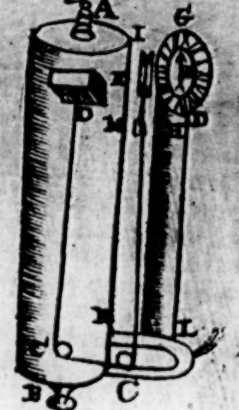


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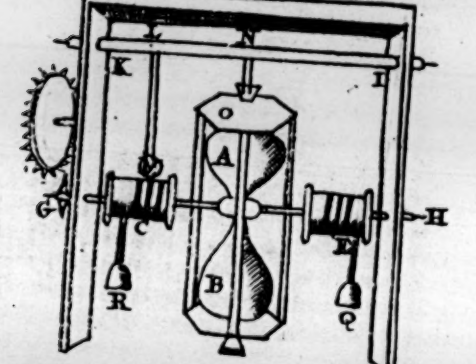


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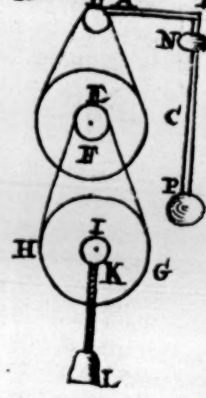


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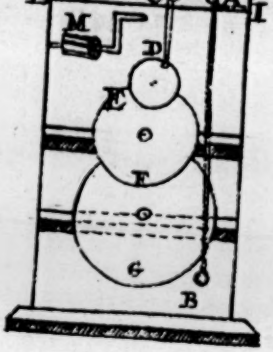


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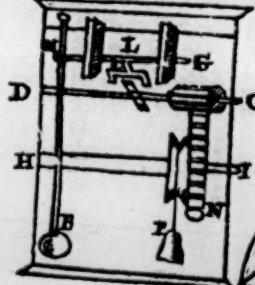


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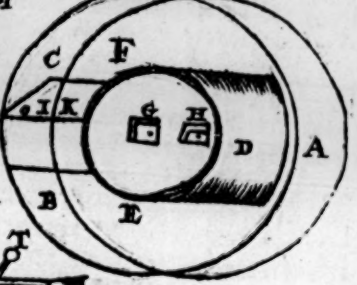


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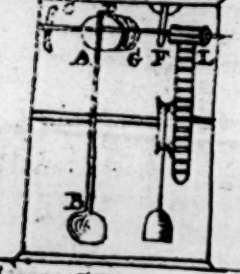


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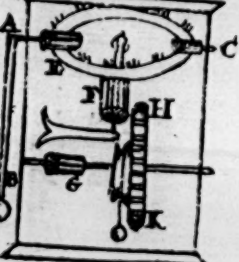


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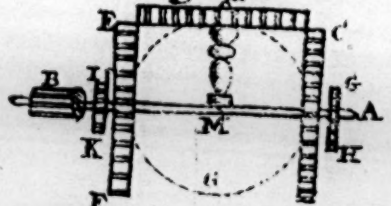


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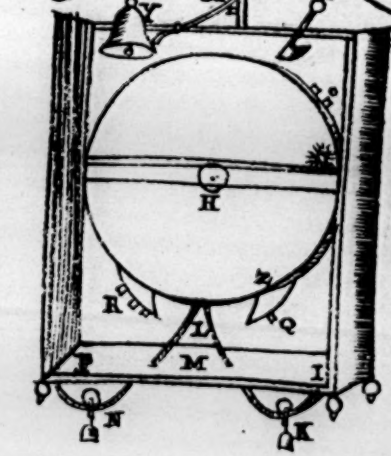


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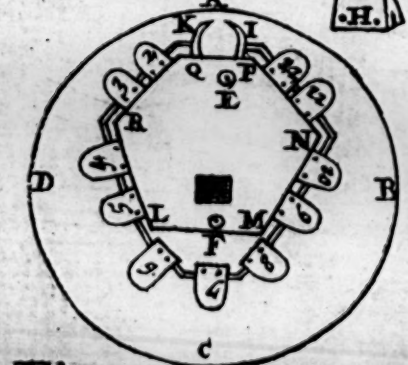


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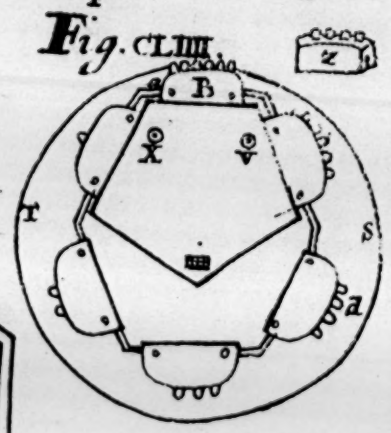
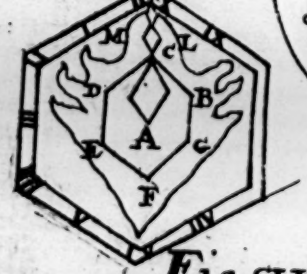


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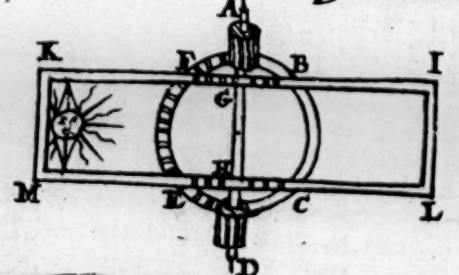


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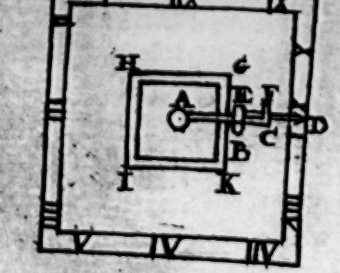


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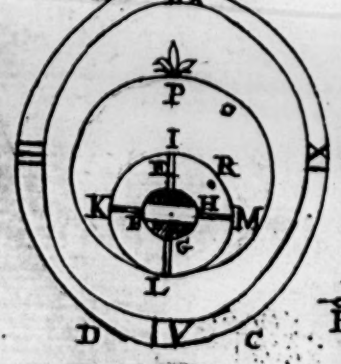


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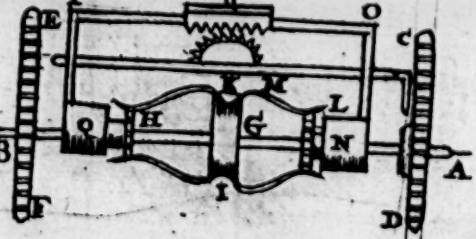
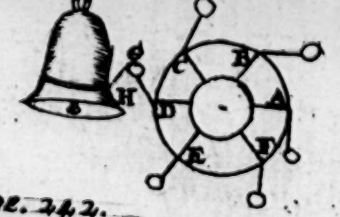


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Problem XXVI.

To procure excited Sounds at appointed times by many Artifices.

THis Father *Schottus* teaches at Proposition the 25th. thus, inclose a Steel spire with two little Wheels and a little Hammer, within a little bell, and this little Engin stands upon 3 or 4 feet, and hath a little tongue sticking out downward, by which the steel spire being first bent, the motion is imparted to the little Hammer; If then the little Engin be placed above the Index of the clock lying Horizontally, or applied vertically about the centre of the Index, the feet of the little Engin being stablisht, and that little tongue sticking out, directed to the line of the hour which you desire to excite, then the Index of the Clock being conveyed to the little tongue, and opening the inclosure of the little Hammer gives the stroke required; and after that whensoever you please to remove it you may, and put it again to the little Engin.

Fig. 162. Secondly, if a Clock be required shewing only the hours, and to hang to the wall of a room; In the wall nigh which the weight of the Clock descends fasten in A a little arm, or Leaver A B, movable in A, on the end of the Leaver B, bind one end of a small chord, than to a little Bar fixt in C cast over the other end of the small chord, to which bind a little spar or piece of a stick C D; lastly, fasten a third little Bar in E, within which and the end D of the stick put the light stick E D between, so that it may stick fast between the little bar E and the end D of the spar or piece of stick, and the weight G being hung will therefore stick fast, under which you must put a brass bason, or such like body of sound, in which the weight G falling, excites a sound; then lift up the weight F impelling the Clock, to so many hours as you desire it to excite, for the weight E being ellapst in a determined time, the stick being conveyed slowly to E D bares it down, and casts it downwards: And this obstacle being taken away, the stick C D being loosed sends down with a force the weight G into the bason underneath.

Thirdly, for excited sounds for Souldiers, or Husbandmen, to a determined time, you may prepare them easily in this manner, take a piece of match, such as Souldiers use, of one thickness and density every where, try diligently how much the fire will consume of it in an hour, then allowing the length of the match for as many hours as you please, note the end, and extend the whole in length upon some piece of timber in an Horizontal site, and a little elevated from the earth: Then in the first sign noted in the match, bind a little chord, and to the same some weight, *viz.* a stone, and the other end of the rope or chord bind about and make fast to somewhat, as to a wall, or a tree, &c. for it will come to pass, that when it hath burnt to the noted sign, it burns or destroys that end of the little rope, and the stone falls into some Vessel or table placed just under, it and so makes a noise.

Many other such like may be thought on which may either be applied to Clocks, or may effect it themselves, that at an appointed time they may waken and raise up them that sleep by some noise; For in the first place all kind of Clocks which we have described before, to wit, which are moved in descending by an inclined plane, that may easily be done, if while they come to such a line of the hour, they run against some obstacle, from whose repulse or removal, a sound is made, or some other noise excited; *Secondly*, we may obtain it by all hour glasses of sand or water, for being increased by degrees by the weight of the water or sand falling down, it may be made, that when it increases to such a magnitude the other weight shall prevail, which either lifts it up, or being freed from the Impediment it shall fall down, &c.

Problem:

Problem XXVII.

*Divers Ornaments applicable to Clocks, and such like
Engins.*

THE Ornaments which may be added to Clocks, and other Chronometric Engins, are innumerable, for besides those which belong to their Indexes, and the other before mentioned, the ingenious Artificer may easily invent many other, some whereof we will shew briefly.

First, a Clock may be made which not only declares the hours and quarters, but also the minutes and seconds, and that either with divers little bells, or by a musical Instrument of Chords or Pipes.

Secondly, the noise of the foresaid Harmony may be made, either before those strokes can publish the Musical consort, not only in small bells, or any other Instrument, or also more together, which may easily be done by Phonotactic Cylinders, as is shewn before; and not only by those Cylinders, but also by an oblong plane, to wit, if you have a thick plate of mettall or a wooden table, to which fasten so many small bolts, or pins, and distant a due proportion between themselves as the Musical tone requires, so that while that plane is moved upward and downward to the right hand, or to the left, his small pins sticking out, hits against the Organ, or other Instrument, &c. And this oblong plane may be moved here and there by a retrograde motion, as is said before concerning the Index of the like plane at Problem. 17, in which case, notwithstanding it behoves the whole thing to be doubled, to wit, one answering to one half of the oblong plate moved in one part, and the other to the other half in the return of the same plate.

That the Clock, or Instruments, may be rightly applied, the following things are to be observed. *First*, the toothed Wheels of Clocks which the Cylinder turns about, ought to be scituate in the middle of the same Cylinder, or in both ends of it, for if it be applied to one end only, some inequality easily happens to the motion, by the resistance of raising the Ham-
mers,

mers, or depressing the little hands, &c. and the Cylinder must be exactly turned: *Secondly*, for each small bell (if you will make the sounds on bells) let there be two Hammers, two little hands, and two rows of holes in the Cylinder, to wit, that any note although short in the tune, may be exprest, when they are doubled, or repeated many times, for if those notes be many, to wit, tailed or twice tailed following immediately, it cannot so well be struck by one Hammer, and presently raised. *Thirdly*, the fewness of holes for one touch, may be supplied by the diversity of small pins, more or less, stretched out without the hole in which they are fastned: *Fourthly*, to greater Hammers, or greater resistings of Elevation, Poisers or weights must be hung as much as need requires; *Fifthly*, the little hands and small pins, are most exactly of a length. *Sixthly*, for accelerating the motion of the Cylinder, those wings which catch the wind, or small weights instead of them, are movable, that they may be moved more or less to the Centre of motion. *Seventhly*, when the motion of the Cylinder acted by weights, is slower in the beginning, a stay must be put between, of one touch, or a touch and an half, to gain the Impetus, before the little keys or pins begin to publish the strokes: *Eighthly*, if the Consort of musick preceed the strokes of the hours, care must be taken that the key opening the striking Wheel of the hour be movable, lest when the tunes are some shorter than others, the stroke of the hour may be a long time expected.

Thirdly, as Indexes of Clocks, and other Engins, belong to the Sense of the eyes, and of the sound to the hearing, so to the same hour measurers, other ornaments may be added, which belong to Odour or smelling; for it may be made that every hour, or at other appointed times, a box or small cistern may open, in which some odoriferous body smelling very sweet is close shut, and the Odour will disperse it self into the whole room; in like manner cocks of small fountains may be opened, sending forth Odoriferous liquors, which liquors may be divers, according to the diversity of the hours of the time; yea, they may be so fine and full of Spirituous rectification, that they may resolve into air, and by their subtilty vanish, their Odour only remaining: Neither is it necessary to use many fountains or spirital Engins, if so be you make a small Engin, out of whose cock only, divers liquors run forth every hour:

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Fig. CLXXIV.

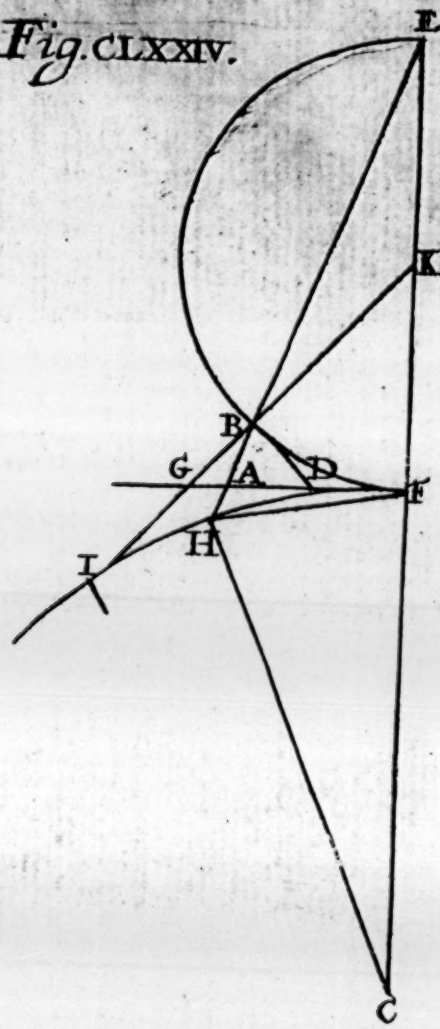


Fig. CLXXV.

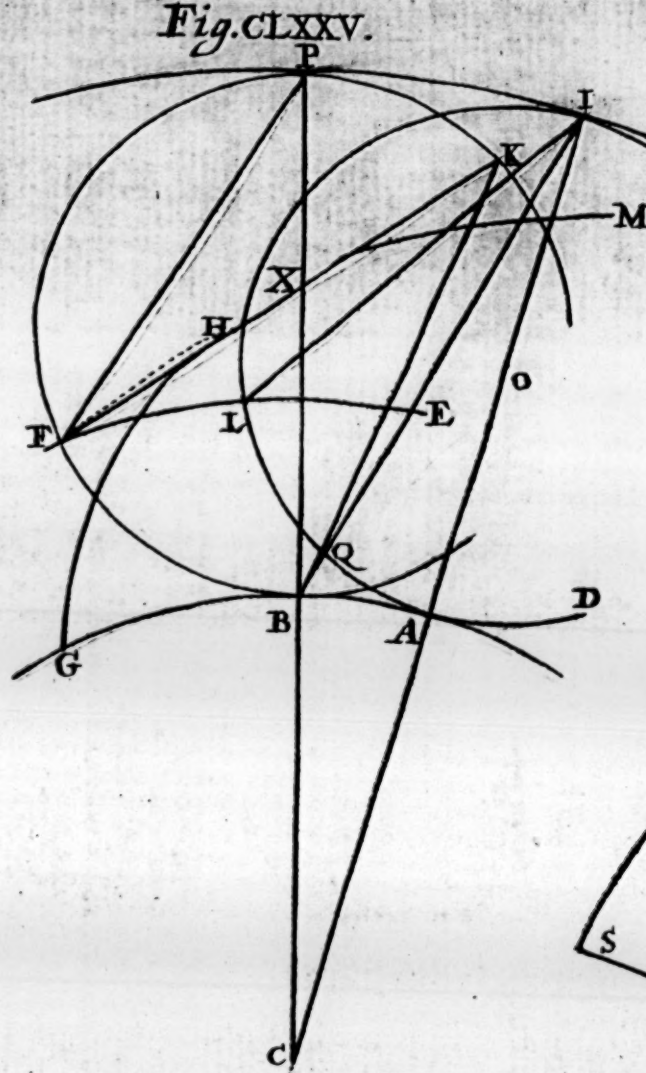


Fig. CLXXVI.

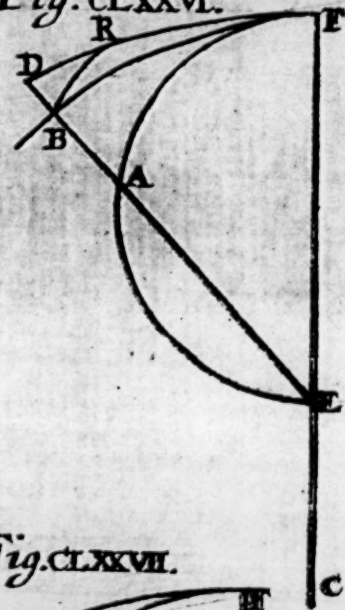


Fig. CLXXVII.

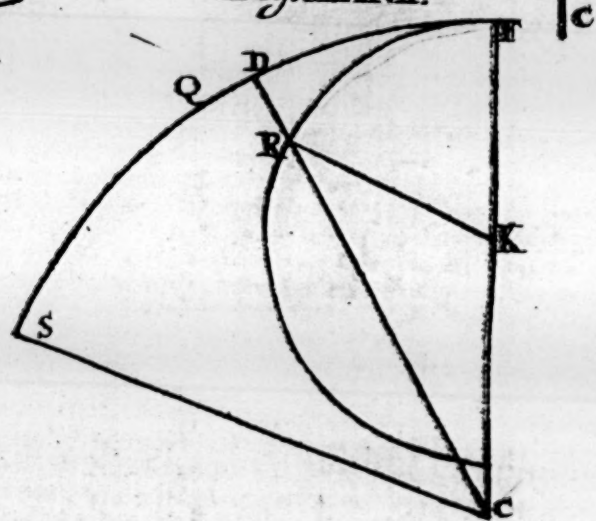


Fig. CLXXVIII.

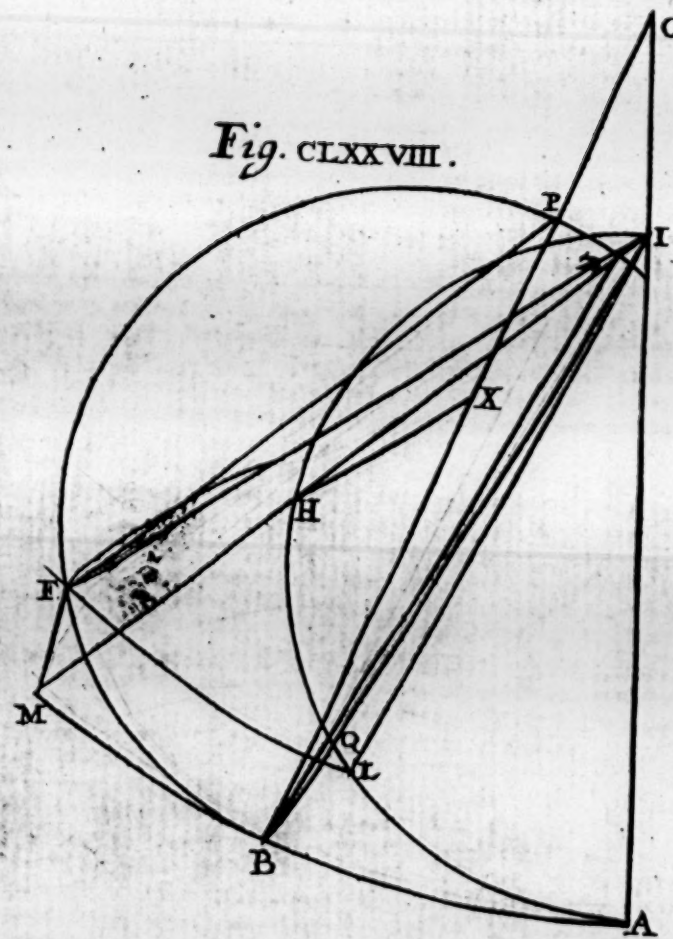
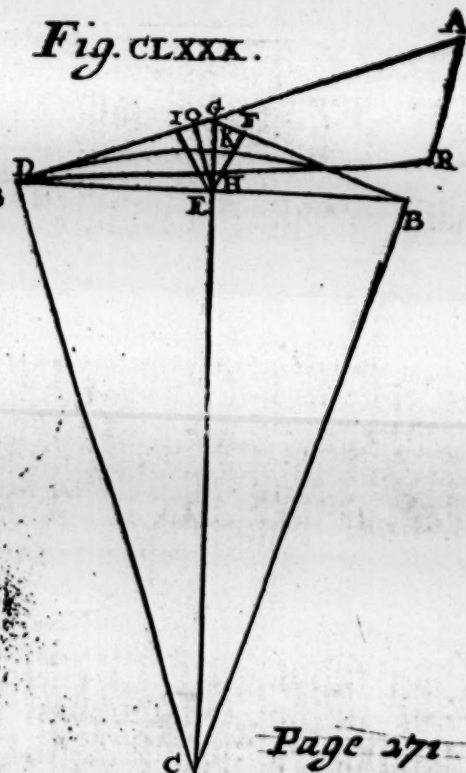
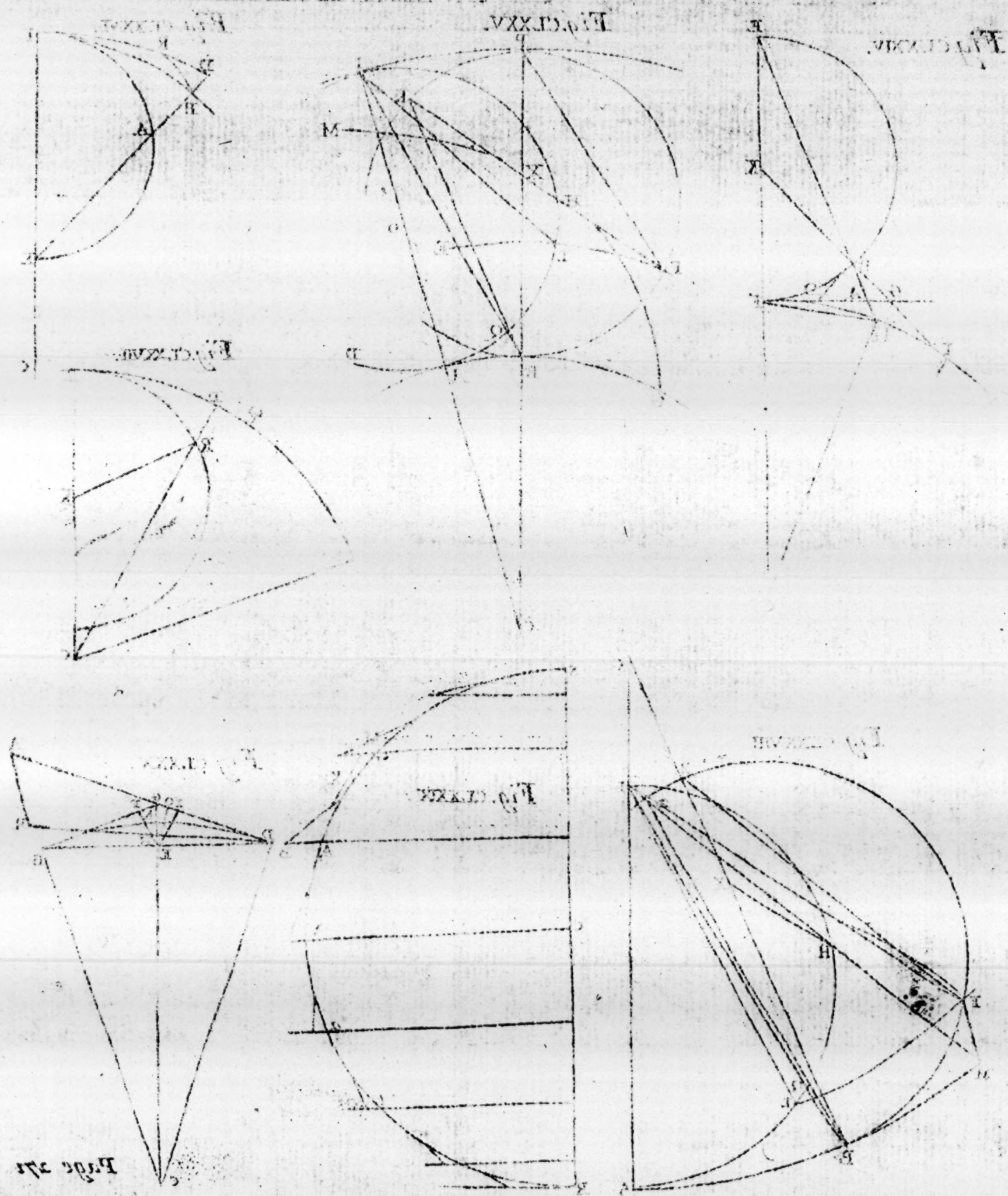


Fig. CLXXIX.



Fig. CLXXX.





Book IX.

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Also Odours may be made either by means of perfuming fire which may be excited every hour, to wit, by percussion, that the next sweetned matter may be burnt; Or being moved into an occult furnace, or lamp, the matter may be moved to them, or rather those to it.

Fourthly, It may be made, that the clock every hour or appointed time, shall atchieve divers offices of trust, as it were a servant, and be dilligent in the Bed-chamber designed to various Offices; so Cloks may be made which at a prefixt time of night shall strike fire and kindle a light; and in the same manner they may be so fitted, that they may send forth water from a fountain, at certain hours for the washing of hands, or draw it from a well, or so as to snuff candles dexteriously, at appointed times: Also a clock may be made, which being placed on a Table, may represent *Bacchus* sitting on a Tun, and at certain times fill pots with divers kinds of wines: Also a Statue may be made in the top of the Clock Turret, that may unfold a streamer in the morning, and fold it up in the evening; and many other such like as these may be performed.

Lastly, other Instruments may be added to Clocks which may shew the degrees of heat and cold, and also of moisture and dryness, or which shall foretel when it will be rain and when fair weather, yea, and they may shew the winds at any time in an inclosed chamber.

Problem XXVIII.

To make a Chariot, or ship, with an Index of Miles, for the measuring of a Journey.

Fig. 163. **M**Easure the compass or Periphery of the Chariot Wheel proposed, and for example let it be ten feet; To the Axis of this Wheel A B, fit a small tooth E, running on another Wheel C D, furnisht with 50 teeth: Again this Axis I E must have a small tooth, like to the small tooth of the former Wheel in E, which folds into the teeth of the:

the Wheel E F, divided into 12 equal parts, each of which consists of 10 teeth, so that all the teeth of this Wheel are 120; Moreover in its Centre G an immovable Index is disposed, which will tell the number of Miles and hundreds of Paces that hath passed by the Chariot in the Journey; for each circumvolution of the Wheel A B, that is, every two paces that is made in the Journey, one tooth of the Wheel C D is moved forward by means of the small tooth C, and therefore since the Wheel C D is furnished with 50 teeth, its whole circumvolution will be compleated after 100 Paces, and then it moves forward the Wheel E F by means of the little tooth E; then since every part of division of the Wheel E F consists of 10 teeth, after every 10 circumvolutions of the Wheel C D; that is, after 1000 Paces, or one mile of the Journey, the Index after that will note another number of Miles; in the same manner altogether the thing may be done in a Ship, provided that a Jagged Wheel like to the Wheels of Mills be so fitted to the side of the Ship, that it may freely move about the axis, while its Jags hit against the water; and this Wheel will be instead of the Wheel of the Chariot A B, to which others are added, as we have said; for the whole Artifice consists in this, that the circumvolution of the first Wheel which answers the length of the Journey be multiplied proportionally to the other Wheels C D and E F, which may be done easily, and divers ways.

Problem XXIX.

The method of making Archimedes's Screw for the raising of water several ways.

Fig. 164. **A**rchimedes his Screw is no other than a Cylindrical Column, on which a Tube is wound about spirally, or in the nature of a screw, as appears in the annexed Scheme, where A B represents the Cylinder in an inclined site to the Horizon, and C D shews the Tube drawn about it spirally; and this Tube if one end of it have an open mouth C, put in the water, so that the water enter into it, and then the
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Book IX!
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Cylinder being duly inclined, and it being turn'd about by the two poles, or ends of the Axis E F that it stays upon, it will come to pass that the water-serpent by little and little will ascend to the top, and run out at the other mouth D.

This ancient and most ingenious Engin, owns the most Ingenious *Archimedes* for its inventer, which first used it to empty water out of the great ships of *Hiero*, King of *Syracuse*; then the *Egyptians* used the same, (witness *Diodorus Siculus*) to draw out the water from the fields drowned by the River *Nyles*, and *Cardan* in his book *de Subtil*, makes mention of a Blacksmith that made this kind of Engin, and imagining himself to be the first inventor of it, for joy ran out of his wits.

How much the Cylinder, or its Axis E F, ought to be elevated above the Horizon is not easily determin'd, as will appear by what follows, although commonly Mechanics (with *Vitruvius*, Book 10, Chap. 11.) require such an inclination as constitutes *Pythagoras* his triangle E G F, to wit, such that the side or Base E F which resembles the Axis of the Cylinder shall be to the side E G, which is the Horizontal line, as 5 to 4, and the side E G in which the other side F G falls perpendicularly, is to F G as 4 to 3.

And the Tube and its Spire must be so fitted about the Cylinder, that each Spire be more or less inclined, and more or less nearer each other by turns.

Besides to the same Cylinder, (which may be greater or smaller) there may be put about, two, three, or more Tubes, so that one successively after another may draw the water beneath, and may pour it out in the same order above.

Some hide the Tube, or Tubes, within the hollow of the Cylinder; or they make the whole cavity, except the Axis in the middle, into a Spiral pipe, or Channel, after the manner of winding stairs, for first they make the Channel spirally about the Axis of small timber, then afterwards they cover the whole all over, that the whole Engin seems a meer Column, the mystery lying hid within; Father *Christopher Grumberger* made a transparent Channel, or spiral pipe, covering it over with a Selenite stone, or looking Glass, that it may appear to the eye looking on it, how the water ascends.

If about the Cylinder you fit little boards such as is used in mill Wheels, or a Wheel furnish'd with little boards be fitted about the same, near the lower part B, this part may be so kept above the

water of the River flowing, that the little boards may be forced by the water, and turn about the Cylinder, for so the water may be conveyed from the River into a meadow, or any other place that you will have it.

Moreover you may raise water to any height in a narrow place, *viz.* within a Tower to the top thereof, as we have known done at *Augusta* in *Germany*; to wit, if the spiral pipes be multiplied, so that the water being raised by the lower spiral, and being poured out in *D* into some receptacle, or Cistern; hence it may be raised higher again by another Spiral, and so successively by more spirals, as high as you please, all which Spirals may be moved by one power, *viz.* by the water of a River underneath, or by another animated Power.

Thus much as to the making and common use of the Screw, or Spiral pipe, and you will scarce meet with any thing else among writers, but that which contains the reason wherefore the water ascends by the spiral pipe, contrary to its natural gravity, you will hear the same story among all of them that I have read; water indeed always descends in the spires of a Tube, and flows naturally to the lowest place, but nevertheless in the mean while by turning round of the Cylinder 'tis conveyed to a higher place; likewise the weight of the water it self, while it advances the spiral Tube, or pipe, helps its advancement: Some say 'tis done by a certain mixt motion joyn'd together, of the descent and ascent of heavy bodies, which while they affect to descend by their proper motion, they run through the Spiral of their own accord, and the spiral by the turning about of the screw, the weight running down leisurely, and obliquely and as it were by stealth, raises it up by degrees, I say, you will find these, and such like expressions, or meer words which sound altogether the same thing.

That we may therefore shew the true cause of this motion clearly and manifestly without ambiguous words, we must observe some Experiments approved by us.

First, Not only water, or other Liquor, may ascend by the Tube of the screw, but also one, or more Globes of any solid metallic matter.

Secondly, by how much greater swiftness the screw is turn'd about, not only a greater quantity of water ascends proportionally to the greater swiftness, as if the motion of the screw be doubly swifter, the quantity of the water will be doubly greater.

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greater, which in equal time will be poured out of the upper mouth of the Tube, but a much greater proportion, so that it may happen that the motion of the Cylinder about its axis being put double, the quantity and consequently the velocity of the water ascending is triple, or also quadruple, or quintuple; and this appears clearly, if instead of water we place Bullets, or small metallic globes in the channel of the screw; for it will come to pass sometimes, that the screw being turn'd about, the Globe will ascend but very little, or if it ascends a little, it presently slides or falls down again in the Tube, but the velocity of turning about being increas'd, it only ascends, all the other circumstances remaining the same.

Thirdly, the lesser the axis of the screw is elevated from the Horizon, the greater plenty of water ascends, and with more ease, so that the screw be turn'd with the same velocity, and all other things alike.

Fourthly, There is not the same proportion of quantity of water ascending through a narrow Tube of a screw, to the quantity of water ascending through another broader Tube, as is the Basis of the narrow Tube to the Basis of the broader Tube; for example, let the narrower Tube be A, and the Tube B doubly broader (or as broad again,) I say, through the Tube B there does not ascend a double quantity of water the other things being alike, but less then double, and therefore if there should be two Tubes of A, and only one Tube of B, although the largeness of this, or the inward cavity be equal to the double largeness of the other two Tubes, notwithstanding it will not draw an equal quantity of water, so that they are all of an equal length, and in the same manner alike, or the screws are turn'd alike.

These things being noted, I say, in the first place, that 'tis false which they commonly affirm (as is said before) that the water does descend in any manner in the Tube of the screw, and much less to make a mixt motion by the ascent and descent: And this appears in the first place chiefly by an experiment of a Globe turn'd about in a Cylinder through a glass Tube, so always ascending as 'tis never discern'd to descend (I speak in respect of the Tube) for it runs towards the upper part of the Tube, never going back untill at length it break out at the upper mouth of the Tube; the same which appears in the upper

superficies of water ascending; and certainly it seems to be implied in the terms that the same heavy body should ascend and descend together at the same time, for it will be moved together with two opposite motions, which is contrary; as we have shewn before.

The reason then why the water, or Globe, or any other heavy body, ascends through the spiral Tube of the screw, ought to be sought from the adherence of the water, or other body, to the inward superficies of the Tube, either from some roughness of the same superficies, or also of the solid Globe ascending, by reason of which the motion of bodies is hindred in their descent by an inclined plane, which how it happens in the screw will be easy to explain from what is said.

I say, then the water, or Globe, doth not always move in the Tube, so as always to go forward further, but by some little space of time, wherein the Cylinder is turn'd about, the Globe rests in the same part of the Tube; but because the same time, in which the Globe rests with respect to the Tube, that part of the Tube on which the Globe rests, ascends by the turning about of the whole Cylinder, it comes to pass also, that the Globe resting in that part, in the mean while is raised higher from the Horizon, and the other parts of the Tube immediately following, obtain a lower site with respect to the Globe, which therefore are constituted in a plane somewhat inclined; then the rest of the Globe ceasing in that part of the Tube, it descends by that inclined plane to the lower part, and there it rests again (for as much as if it should pass further, it ought to ascend, which is contrary to its natural gravity) and while it rests in that part, 'tis transfer'd again together with the Tube into an higher site, from whence it again rolls down by another inclined plane on the other part of the Tube; and so by degrees is moved forward even to the upper mouth of the Tube; and the reason of this interrupted motion, or interposition of rest, is, as I said, the adherence or roughness of the superficies both of the Tube and also of the Globe; for it comes to pass that by some little stays the motion is intermitted, while the movable body finds resistance in the rough plane.

Fig. 165. And there is another reason besides the foresaid resistance of Roughness, or adherency of bodies, which very much moves forward such motion: to wit, the imprest Impetus

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petus of motion in the opposite part of the Globe, or water. Let the Horizontal line be A B, above which the axis of the screw A C is raised, and let the spiral Tube be D E I L M N. Now, for example, if the Globe of lead be in part of the Tube E, and the Cylinder be turn'd about with a motion from E towards G D; while the Globe rests a little in part of the Tube E, in as much as that part together with the Globe resting is raised by the turning about of the Cylinder into a place nearer the horizontal line, *viz.* into P, and in the mean while, the part of the Tube H is depressed to Q; from whence it comes to pass that part of the Tube is constituted in the inclined site P Q, and therefore the Globe, which was found in P descends through that part of the Tube, or inclined plane from P in Q, where you see now the Globe advanced higher above the Horizon; for the point Q is more distant from the Horizon A B, than the point E, where the Globe was before; again in Q, because of some resistance which it cannot overcome through the little stay of time resting, 'tis raised as before with part of the Tube in the same point Q, then answering to the time, from whence again after resting, it falls down in the other part of the Tube, and so successively in descending it truly ascends, but not so as to ascend in the same time in which it descends, and therefore it cannot be said, truly speaking, that it ascends in descending, nor that that motion is properly composed of ascent and descent. Wherefore it ascends in that part of time in which 'tis hindered by the adherence to the inward superficies of the Tube, or its roughness, that 'tis not moved forthwith, but it descends after that small stay, or little rest, and because it descends more oblique than before it ascended, therefore the descent is less, consider'd absolutely and in a perpendicular line than is the ascent; and therefore after all the descents it will be found higher above the Horizontal line.

Add, that after each descent, to wit, after the descent from G in E, it doth not presently rest in the lowest place E, due to it naturally, but by the acquired impetus in descending by the inclined plane G E, it ascends also further, *viz.* to H, especially since the point of the tube H descends in the mean while, and passes away the globe, that therefore it may shun the steepness from E in H, by being successively lighter, and ascend easier.

Finally,

Finally, to the facillitating of this motion of the globe the imprest Impetus of the tube concurs to the opposite part of the motion of the globe, for it is found by experience, that the Globe descends more swift on an inclined plane, being moved (for example) from the East towards the West, if in the mean while that it descends, the inclination remaining the same, the plane be transfer'd by an opposite motion, to wit, from the West towards the East; since therefore while the Globe descends, by the inclined part of the Tube from G in E, or also while it ascends further from E in H, the Tube by the Circumvolution is moved by an opposite motion from H towards E and G, it come to pass from such motion, or from the opposite Impetus of the Tube, it acquires a greater velocity: But likewise this must be observed, that as often as the opposite Impetus of the Tube, or of the inclined plane avails to the velocity of the motion of the globe, so often the Globe suffers some rubbing or wearing with the plane that lies under it: Wherefore from the beginning to the end, all the reason of the motion of the Globe in the spiral Tube of the screw, seems to be founded on the foresaid adherence, or resistance of bodies in the contact of superficies. And what we have said concerning the Globe, the same may altogether be said of water, or of any other body, notwithstanding we have made use of the Globe, in the example, because if the experiment be made, as we have oftentimes done in it, all these things clearly appear, which hitherto we have said; And that the Globe may be manifest to the eye, and the reason of its motion may be observed, either we must make use of a glass Tube, or the secret hollow channel about the Cylinder must be of transparent stone to see through; or you may easily put a double wyre about the spiral Cylinder, so that that Iron thred, or wyre, touch not the Cylinder, but stand above it about half an Inch, and the same distance also between it self, and therefore some quadrangles intercept the space of way, on which the Globe is placed as it were on a channel, or groove.

From what hath been said 'tis manifest, in the first place, how the motion of bodies which are raised by means of this Engin, are reduced to motion by an inclined plane.

Secondly,

Book IX.
Secondly, about with only raise, makes the opposite motion, as water, which is the more the Add, that the Globe rests, that therefore after the descent than before pens from the Globe to the Superficies towards H; wards P or as P, if the Impetus, a Thirdly, above the easier, that turns the C with the ascend, when manifold: the weight but less upon the Horizon weight is from whence ing about is of the water drives again the whole computed that is always inclined) but lar CB; the water existi

Secondly, a reason appears why the turning the Cylinder about with a greater velocity, or more swiftly, that it doth not only raise greater plenty of water proportionally, but also makes the same ascent more abundantly easy; for since the opposite motion of the Tube avails much to the ascent of the water, as we have said, by how much swifter this motion is, which is made by turning about of the Cylinder, by so much the more the ascent of the water is advanced.

Add, that that little space of time which the water or the Globe rests in some lower part of the Tube 'tis raised higher, that therefore the rest ceasing it ought to descend less, and after the descent 'tis now much higher raised above the Horizon than before: moreover, since that little stay of the Globe happens from the impediment, or roughness of the Tube, suppose the Globe to be in E, and some impediment or roughness in the Superficies of the Tube, to be in its way on the part towards H; when this kind of roughness is moved forward towards P or G, and let that which raises the Globe be as far as P, if the Tube be moved more swiftly, it impresses a greater Impetus, and raises it higher.

Thirdly, 'tis manifest also, why if the screw be less elevated above the Horizon, that the water ascends the easier, I say, the easier, that is, with less force and labour of him, or that which turns the Cylinder: (for if the Cylinder being turn'd about with the same swiftmess, an equal quantity of water should ascend, whether it be more or less inclined) the reason is manifold: First, because when the Axes A C are more Elevated the weight gravitates more upon the prop of the Axis in A, but less upon the prop in C, but if the Axis be less raised above the Horizon, or comes nearer to an Horizontal site, the whole weight is distributed to the Props A and C with less inequality, from whence it comes to pass that the Circumvolution or turning about is easier. *Secondly*, and chiefly because the entrance of the water into the Tube by the lower mouth D, resists and strives against the weight or pressure of the water which is in the whole Tube, and that weight or force of pressure is not computed from the quantity of water which is in the Tube (for that is always the same whether the Cylinder be more or less inclined) but 'tis computed from the greater or lesser perpendicular CB; therefore when the perpendicular C B is greater, the water existing within the Tube presses more, and resists more the enter-

enterance of the water by the mouth D, since therefore that force or pressure ought to be overcome by the power turning the Cylinder, as often as the mouth D draws new water, it appears why the screw being elevated higher is moved with more difficulty: Hence you may be satisfied that 'tis false that some say, that water therefore ascends easier by a screw less elevated, because the way and acclivity of motion is lesser, as if water in ascending by a plane more steep is also more wearied, which is foolish: Hence also it is, that a solid Globe is elevated almost with equal facility through the Tube of the screw, whether the Cylinder be more or less inclin'd; for in this case each reason aforesaid ceases, and the second reason ceases wholly, since in each circumvolution of the Cylinder a new Globe is not raised, but that only which is moved forward in the Tube: And the first reason also hath scarce any room, if we suppose the Cylinder alone not to gravitate much upon the Prop or stay on which the ends of the axis rest upon.

And from hence it appears why it cannot be determined, how much the inclination of the Cylinder ought to be elevated above the Horizon; for this ought to be consider'd not absolutely, but with respect to many other things, and chiefly to these three, to wit, to the velocity whereby the Cylinder is turn'd about; for if it be turn'd about more swiftly it may be more elevated, and nevertheless the water will ascend through the tube. Secondly, to the greater or lesser adherence of the water, or other Liquor, to the inward superficies of the spiral tube; for when this adherence is greater, the water doth less gravitate upon the lower mouth of the Tube, and besides it more easily contains the Impetus from the motion of the Tube in that manner which is shewn a little before. Thirdly, and chiefly to the obliquity of the winding compass of the Tube, for if the spiral or winding compasses be thicker and closer together, and more near each to other, the Tube will be longer, and therefore the way and motion of the water longer before it comes to the upper part of the Tube, but nevertheless by reason of the greater obliquity of the spiral, the lower water gravitates less, and ascends easier, and therefore the Cylinder may be raised higher above the Horizon.

According to the variety therefore of these circumstances the inclination of the Screw may be varied: Notwithstanding this universal precept must be observed, to wit, that the Cylinder

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A C be never elevated above C, to such an height, that the spiral of the Tube DE or IL or MN appear parallel to the Horizon AB; for the point of the Tube D ought to be higher than E, and the point I higher than L, and so of the rest; otherwise the water being in part of the Tube DE, will flow out at the mouth D before it be moved forward any further in the Tube.

Fourthly, from what is said, that question may be resolved, to wit, whether or no 'tis most convenient to have one large Tube to turn round with the Cylinder, or many small ones: Father *Grymberger* affirms, that if one spiral Tube circumscribe the whole Cylinder, such a simple screw will pour out as much water, as if there were many Tubes, and somewhat more, and he assigns this reason, because many spirals of a Tube by reason of their thickness which they must have ought to occupy more room in a Cylinder than the thickness of one. But although this be most true, yet our question is not whether more water may ascend by one Tube only than by more; for example, unless three Tubes taken together are equal to one other larger Tube, 'tis certain that greater plenty of water may ascend by that one larger Tube; but the question is, whether or no supposing that those three Tubes, be exactly equal to the Capacity of one larger Tube, and let the Cylinder be capable, that is fitted either to the three small Tubes, or to the other larger one, I say, 'tis to be consider'd, whether to make use of the one large one, or those three small ones?

And to this Question I answer, It would be better to use three small Tubes (so that they do not gravitate more by their weight on the prop sustaining the Cylinder) than one larger; and not only because (as we have said appears) in the fore-said experiment) that they raise more water; but likewise because it ascends easier, and with less strength of the power moving the Engin. The reason is, because although the three Bases of the lesser Tubes be equal to one Base of the larger Tube, and they are supposed all of an equal height, nevertheless it gravitates or presses less in the triple base, or in the lower mouth of the smaller Tubes, than the water gravitates in one base only, or in the mouth of the larger Tube, and that therefore because although the Capacity of the three Tubes be equal to the Capacity of the one Tube, nevertheless

the inward superficies of the three Tubes is at least doubly greater the inward superficies of the one larger Tube, and since the adherence of the water is greater where the superficies is greater to which it adheres, and since it ascends easier and gravitates less upon the base when the adherence is greater, it appears to gravitate less on the bases of the three Tubes, and in them the water ascends more easily. I add also, that the water is easier drawn if it be drawn successively by many Tubes by one circumvolution of the Cylinder, than if the whole be drawn with one turn by one Tube.

From the foresaid greater adherence of the water of the smaller Tubes it comes to pass also, that although the Cylinder be turn'd about with less swiftness, yet the weight of the water cannot so easily overcome that adherence and fall back again downward, as happens in wider Tubes, which unless they are moved swiftly the water by its weight easily goes back more.

Hence also we esteem it a thing not altogether impossible to make a screw with such artifice, that by means thereof the perpetual motion may be obtain'd, for the ascent of water or of other heavy bodies seems easiest of all by the screw.

And that this motion may be rendered yet easier, some ingenious things occur to my mind which I believe may be made use of with some profit.

The first is, when you put one or rather more Tubes about a Cylinder, within each of which you may put cotten thred, extended from one end to the other; for by this means the adherence of the water increases, and creeps along more easily through the Tubes, although the quantity be less, all one as if one large Tube were divided into many small ones.

Fig. 166. The Second is, since the rubbing or wearing of the Poles of the Axis on the Prop or stay on which they rest, is the chief impediment of all, to the Circumvolution of the Cylinder, and since there is a greater rubbing and resistance on the lower Prop A, by the greater gravitation there than in B, the rubbing may be hinder'd, if not wholly, at least in great part, by affixing a Wheel, or rather a Tympane CD, to the lower part E of the Cylinder AB, which Tympane must be hollowed within or void, not only the lower part D, by reason of its lightness will swim upon the water, but also it will sustain the Cylinder,

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Cylinder, so that its Pole A within the notch of the Prop may be turn'd about without any resistance.

Fig. 167. The third is, that the Cylinder be made of light matter, for the lighter it is the easier 'tis turn'd; wherefore it will be sufficient to fit the Tubes so, and to turn them about in Spirals, that they will need no Cylinder to sustain them; for it will be sufficient if in the extream heads of the Tubes, you fit two little Wheels A B, C D with their Axes fixed in the Centers. For unless they be very big and large, and the Cylinder very long, they cannot easily be bent by the water, or by their proper weight, and especially if they are made of rough matter, *viz.* of thin Iron plates cover'd over with Tin or Glass, &c. Or if you fear the bending of the Tubes, you may fit here and there in stead of the whole Cylinder, two or three rulers extended according to the length from A to C, and from B to D, which rules or Spears support the Tubes, least they bend in the middle. Likewise you may so turn about many small Tubes spirally, one immediately near to another, that they being all united together, make one whole Cylinder, or rather a Tube, which resembles a Cylinder made hollow within.

Fourthly, If you desire to raise not Water but a solid Globe by a Pulley, you need not make use of a Tube; two iron wyers turned about spirally parallel to each other, and fastned to the extream heads in the Circumference of the little wheels A B and C D, will be fit for that purpose; and those wyers ought to be somewhat less distant from one another, than the thickness or diameter of the Globe; for so the Globe will be detain'd within each wyer always in the lower parts of the spirals, and will ascend by degrees by those spirals being turn'd about.

Fig. 168. Also it may be made of two thin plates of Mettal, or of one only made hollow after the manner of a Channel or Groove; yea, we have made a screw fit to take up a leaden Globe or Ball of an inch Diameter, of thick paper or pastboard turn'd about spirally, to wit, the Tube of them which compose a Telescope we have cut spirally, so that the Globe is detain'd within the spiral cleft, and will ascend by the same cleft, the Tube being turn'd about. Moreover one plate of mettall only may be turn'd about a Cylinder which ascends spirally, and sticks out every where above the superficies of the Cylinder,

one or more inches, according as the magnitude of the Globe to be raised requires, and the plate must be of such a breadth, as is the Diameter of the Globe, or a little more, and erected perpendicularly upon the superficies of the Cylinder, and one of its sides fastned to the same Cylinder; then the Cylinder being elevated in an oblique site to the Horizon; for Example, in the site A B, and the Axis leaning or staying upon its prop, the hollow plate of mettall D C is fitted under the Cylinder, which remains unmoveable in the same oblique site, and then being distant a little from the spiral plate, so that as it were, it is razed by the subjected channel or hollow plate being turn'd about. Then if you place a Globe on this, and turn about the Cylinder, the spiral will move forward the Globe by that inclined Channel from D in E, and from E to F, &c.

The same power or strength must be applied here, as a screw hath to raise water, or another body, of which we have spoken elsewhere concerning the common Screw; for as you see the motion or elevation of weight by this screw of *Archimedes*, is indeed a motion by an inclined plane, where that universal principle always takes place, that the increase of force is taken from the proportion of the velocity of the power moving, to the velocity of the weight moved; wherefore, if for example, as in the present figure the spiral being four times turn'd about, the Cylinder be 12 feet, and the Globe ascend from D to F, in the plane or inclined Channel D C. two feet, the power as 2 may raise the weight as 12.

What we have said hitherto concerning a Cylindric screw, may also be understood of a Conic screw, for instead of a Cylinder we may use a Cone to which the Tube may be spirally turn'd about, as is commonly known. And although some prefer a Cone before a Cylinder, yet we see not any effect that it performs better; therefore since a Cylindric screw is easier prepared, we may use the same most safely, and perhaps most profitably, at least in many cases.

Many other things occur which may be said concerning this Engin, which in our opinion are very Ingenious, for writers have scarcely shewn any thing worthy of consideration to Posterity in this matter although it be very capacious, as may be easily understood from those things which we have briefly shewn, with which we shall conclude this ninth and last Book of

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of *Mechanick Powers*. Giving all honour and Praise to that great Master of Arts, and Fountain of all Wisdom, the Omnipotent God Blessed for evermore.

I had here put an end to *Mechanick Powers*, but meeting with some new inventions relating thereto, lately publisht in France by an able *Mathematician*, which if put in practice may be useful and beneficial in Engins; I thought fit to add them by way of Appendix, and they are these that follow.

APPENDIX.

BOOK X.

Of Epicycloids, and their use in Mechanicks.

Definitions.

Fig. 169. IF the circle ABD be rouled or turn'd about upon the arch *A b d* of any Circle, the point D which is the extreame or end of the Diameter AD, will by its motion describe the Line D 14, 15, 16, 17 *d*, which is called an *Epicycloid*.

The circle ABD is called the generating circle of the *Epicycloid*.

The arch *A b d* is the Base of the *Epicycloid*.

If the generating circle roul on the out side of the circle of the Base, the *Epicycloid* is called *Exterior*, or *Outer*: But if the generating circle roul on the inside of the circle, the *Epicycloid* is called *Interior*, or *Inner*.

The space contain'd by the *Epicycloid*, and by its Base, is called the *space of the Epicycloid*.

The

The Dimension of the Space of the Epicycloid.

Lemma 1.

Fig. 170. **L**ET the Semicircle be $APpB$, whose diameter is AB , and its centre K ; having drawn the line Pp Parallel to AB , and meeting the circle in the points Pp , from any point C of the diameter AB drawn longer, draw the lines CP , Cp ;

I say, the sum of the right lines CA , CP , is to the sum of the right lines CB , Cp , as the difference of the right lines CB , Cp is to the difference of the right lines CA , CP ; or else, which is the same thing, the Rectangle made of the sum of the lines CA , CP and their difference, is equal to the rectangle made of the sum of the lines CB , Cp and their difference.

Lemma 2.

Fig. 171. In the Triangle CAV if the right lines PX , pG , BM being parallels to the base AV , cut the side CA , so that the sum of CA and CP , be to the sum of Cp , CB , as the difference Bp the Segment of the last, is to the difference PA of the first.

I say, that the Trapezias Mp , AX are equal between themselves.

Lemma 3.

Fig. 172. Let the Semicircle be $ADEB$, and on its diameter AB prolonged or not prolonged, let the point C be taken, and draw any right line DE Parallel to the diameter AB which meets with or touches the circle in the points D, E ; From the Centre C , with the Semidiameters CA , CD , CE , CB , describe the arches of circles AF , DPG , EpH , BI , which meet with any rightline as CF drawn from the centre C , in the points F, G, H, I .

I say, that the four-sided mixt figures $AFGP$, $pHIB$ are equal between themselves.

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Demonstration.

Make the right line Af equal to the arch AF , which must make with the diameter CA , the right angle CAf ; having drawn Cf , draw also the right lines Pg , pb , Bi , parallel to Af .

'Tis evident by construction that the triangle CAf is equal to the Sector CAF : In like manner, the Triangle CPg is equal to the sector CPG , wherefore if from the equals CAf , CAF , you take away the equals CPg , CPG , the remain will be equal, to wit, the Trapezia $Apgf$, and the four sided mixt figure $APGF$. We may demonstrate in the same manner that the Trapezia $pb i B$, is equal to the mixt figure $pHIB$.

But by the first *Lemma* the sum of the right lines CA , CP , is to the sum of the right lines Cp , CB , as the difference of Cp , CB which is pB , is to the difference of CA , CP , which is AP ; wherefore by the 2d. *Lemma* the Trapezia $Afgp$ will be equal to the Trapezia $pb i B$, and the mixt figures $APGF$, $pHIB$ which are equal to the Trapezias are also equal between themselves.

Lemma. 4.

Fig. 173. If the circumference of the Semicircle ABD be divided into equal parts between themselves in the points $EFG BHI$, &c. and the number of these parts be even and indefinite, and on the diameter AD prolonged or not prolonged you draw from the point Y as a centre the arches of a circle, whose radius's are the distances YA , YE , YF , YG , &c. and let the length of the arch Ad described by the point A be equal to the circumference of the Semicircle ABD , and let the Arch Ad be divided into as many equal parts $efgb$ as is in the Semicircle ABD : Then having drawn the Rad^y from the centre Y to the divisions $efgb$, &c. then you will have the mixt four sided figure $ADXd$ divided into an indefinite number of little mixt four sided figures which will have the following properties.

Because the equal divisions of the Semicircle may be drawn by the points of division of the right lines KE , IF , HG , &c. which will be parallel to the diameter DA of the circle; therefore by the 3d. *Lemma* the four sided figures $d y Rk$, $Xza4$, will be equal between themselves being equally removed

moved from the extrems: But also those which are contain'd between the same circles will be equal between themselves, because of the equal divisions of the arch $A b d$; wherefore the 4 sided figure $A e E r$ will be equal to the 4 sided figure $X z a 4$.

We may demonstrate in the same manner that the 4 sided figure $2 X 4 t$ is equal to the 4 sided figure $d 3 f k$ or $A e 18 q$, and so of the rest.

'Tis evident in each Sector, as $Y X 4$ or $Y d k$, that the four sided figures are equally removed from the extrems, as $2 X$ and $3 u$ are also equal between themselves; for the 4 sided figures $X x$ and $d u$ are equal, the 4 sided figures $X t$ and $d s$ are also equal by the foregoing *Lemma*: Wherefore if the greater be taken from the lesser, the remains which is the 4 sided figures $2 x$ and $3 u$ will be equal, and so of the rest.

Lemma. 5.

The same things being put as before and in the same figures, if you draw the diagonal line $D L M N O d$, compounded of an indefinite number of small right lines, which in the 4 sided figure $A D X d$, divides in two diagonal wise all the small 4 sided figures, which are in the diagonal from the angle D even to d , as appears in the figure, by the lines $D L$, $L M$, $M N$, $N O$, &c.

I say, that the 4 sided figure $A D X d$ is divided in two, equally by the diagonal $D O d$,

'Tis not difficult at all in this place, to grant that the small diagonals which are from right lines, divide in two equally their particular quadrilaterals, or 4 sided figures, and that the difference which is between the true division and this, is not found considerable, and seeing we may always find a less magnitude than any given, because that the quadrilaterals which are divided, are supposed indefinitely small as is commonly accepted in the use of Indivisibles.

Now by that which is demonstrated in the precedent *Lemma*, 'tis evident that the Quadrilater $A L$ is equal to the quadrilater $X R$; In like manner the Quadrilater $e M$ is equal to the Quadrilater $4 Q$; the Quadrilater $f N$ equal to the Quadrilater $5 P$, and so of the rest.

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Wherefore all the like Quadrilaterals together on one side of the Diagonal $DLMNOP$, &c. will be equal to all the Quadrilaterals on the other side. But the line $DLNOPd$ which divides diagonal wise all the small Quadrilaterals which are in the diagonal, is supposed to divide also in two equally all those quadrilaterals; therefore this diagonal, which may be consider'd as a crooked line, divides equally in two all the great Quadrilater $ADXd$; which was to be Demonstrated.

Scholium.

If we suppose that the point Y which is taken on the diameter AD is infinitely lengthned from the circle ABD , there may be right lines perpendicular to the Diameter AD , instead of the Arches of circles, which pass through the points $DKIHA$, of which Ad is one, which is put equal to the circumference of the Semicircle ABD , and which is divided into so many equal parts, as is the Circumference ABD ; and lastly, instead of the mixt Quadrilaterals, or 4 sided figures, as those before, you will have Parallelograms, which being equally removed from the Extrems, will be equal between themselves, and thence it follows likewise that the diagonal which divides diagonal wise all the little Parallelograms, which are from one angle to the other, will divide the whole great Parallelogram into two equally.

Lemma 6.

Fig. 169. The same things being put as before, if you make the Semicircle ABD to set forward, so that the diameter AD be placed on the part $e8$ of the Radius $Y8e$, and that the point A agree with the point e ; 'tis evident that the point L of the diameter will agree, or be in the point L of the Radius Ye ; Moreover if we make it to pass even to the Radius Yf , and that the point A fall on the point f , the whole diameter AD will agree with the right line $f9$, the point m of the diameter of the circle ADB will agree with the point M , and so of the rest: Whence 'tis evident, that all the points of the diameter AD , as $Dlmn$, &c. describe the diagonal line $DLMNd$.

Demonstration.

But if instead of removing the circle $A B D$, we conceive it to roll on the base $A b d$; when the point E of the circle is come to e , the diameter of the circle $E 10$, will be joyned with the right line $e 8$, for by the Hypothesis the arches $A E$, $A e$ are equal in length; and from the same, when the point F is come to f , the diameter $F 11$ will be joyned to the diameter $f 9$, and so of the rest. But if you mark the distances $A l$, $A m$, $A n$, on every diameter, as $E 12$, $F 13$, &c. it is evident, that while the circle $A B D$ rolls on the base $A b d$, the points $l m n 7 p q$ of every diameter meet one another in the diagonal line $D M N O P d$: For when the point A of the circle is come to e , the point 12 on the diameter $E 10$ will be in L , because that the distances 10 , 12 , $D l$ are equal; and by the same reason the point 13 will be in M , &c.

But moreover, when $E 10$ is placed on $e 8$, and the point 12 on the point L , the point D of the circle $A B D$ will be in the point 14 on the arch $l 14 z$: For the Semicircle $8, 14, e$ represents the Semicircle $E D 10$; and as the arch $10 D$ is equal to the arch $D K$ by Construction, when the point 10 by the movement of the circle is come to the point 8 , the point D will of necessity be on the point 14 in the arch $L K L 14 z$; so that the portion $L 14$ of this arch will be equal to the Portion $L K$ of the same arch: In like manner, when the point 11 is come to the point 9 , the same point D will be on the point 15 in the arch $m l M 15$, so that the arch $M 15$ will be equal to the arch $m l$, &c.

P R O P O S. I.

Fig. 169. **I**N the precedent Figures 'tis demonstrated that the space of the moiety, or half of the *Epicycloid*, $A b d 17, 16, 15, D$, is equal to the half of the Quadrilater $A b d X D$, joined to the generating semicircle $A B D$.

Fig. 173. I have shewn before that the line $D M O Q d$ divides the mixt quadrilater $A b d X D$ in two equally; it remains then to demonstrate that the space $D L O Q d 17, 16, 15, D$, contained by the line $D M O Q d$, and by the half of the *Epicycloid* $D, 15, 16, 17, d$, is equal to the generating semicircle $D B A$.

By construction, the whole generating semicircle is divided into mixt Quadrilaterals, as $m l 11 n$, and into two trilled, or
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3 lined figures DKl , rEA : But also the space $DMOQd$ 17, 16, 15, 14, D, is divided by the same circles described from the centre Y, into so many 4 sided, and 3 sided (or 3 lined) figures, as are in the generating semicircle; so that the arches of every circle contains so much in the generating circle which in the space are equal between themselves, as the arch M 15 in the space is equal to the arch M l in the semicircle, which is evident by the formation of the *Epicycloid*: Wherefore the mixt Quadrilater, as L 14 15 M in the space is equal to the mixt quadrilater $LKlm$ in the semicircle, for they have the same breadth, and are inclosed in equal arches: But each of these Quadrilater equal in the circle and in the space being consider'd as Indivisibles of the one and the other, it will follow that the space will be equal to the semicircle; which was to be demonstrated.

Scholium.

Keeping to the same Demonstration, if we suppose that the point Y is infinitely removed from the base A d , which base is a right line in this case, and the Quadrilater A dXD is a rectangle, which is then equal to the generating semicircle A B D taken 4 times, as appears by its generation: Wherefore the space A $b d$ 17, 16, 15, D, will be equal to the semicircle A B D, taken twice together with the same semicircle which is equal to a semicircle taken 3 times; the line $d r6 D$ in this case is called *Cycloid*, or *Trochoide*, and sometimes a little wheel.

P R O P O S. II.

THe space of the outer *Epicycloid* is to its generating circle, as 3 times the diameter of the circle which is the base, together with 2 times the diameter of the generating circle to the diameter of the circle of the base.

But the space of the inner *Epicycloid* is to its generating circle, as 3 times the diameter of the circle which is the base, less 2 times the diameter of the generating circle, to the diameter of the circle, which is the base.

The Dimension of the Lines of Epicycloids.

Of the touching of Epicycloids.

Lemma 1.

Fig. 174. **L** Et the circles be $E B F$, $F H$ which touch each other outwardly in F . Having join'd the centres $K C$ by the right line $E K C$ which passes by the point of contact, or touching F ; from the extream E of the diameter $F E$, draw a right line $E B$, prolonged to the other circle in H .
I say, that the arch $F H$ is greater in length than the arch $F B$.

Lemma 2.

Let the 2 circles be $E B F$, $F H I$, which touch each other in F , from the centre K of one of the circles draw the line $K B I$, meeting them both in B and in I .
I say, that the arch $F H I$ is greater in length than the arch $F B$.

P R O P O S. I.

Problem.

To find the point of Contact, or touching of the outer Epicycloid.

Fig. 175. **L** Et the outer Epicycloid be $G H M$, whose base is the circle $G A$, described from the centre C . And let the generating circle $I H A D$ of the Epicycloid be placed in such manner, that the describing point H be on the Epicycloid in that point in which the touching is made: If by the centre C of the circle of the base, and by the centre O of the generating circle you draw the right line $C A O I$, and by the extream I of the diameter $A I$ you draw the right line $I H$ to the point H .

I say, the right line $I H$ touches the Epicycloid in the point H .

Lemma 3.

Fig. 176. Let the two circles be $F A E$, $F R D$ which touch each other in F , having their convexities of the same side, and that the centre C of the circle $F R D$ be out of the diameter $F E$ of the circle $F A E$; having drawn a right line $E A D$ from the extream or end E of the diameter $F E$, which cuts the circle $F A E$ in the point A , and the circle $F R D$ in the point D .

I say,

I say, that the arch FRD is more in length than the arch FA .

Lemma 4.

Fig. 177. Let the two circles be FS , FR which touch in F , and that have the convex parts of the same side, and let the centre C of the greater be on the diameter of the lesser lengthned; if you draw the line CRD from the centre C which cuts the 2 circles in R and D .

I say, that the arch FR of the lesser is greater in length than the arch FD of the greater.

PROPOS. II.

To find the touching of the inner Epicycloid.

An Advertisement.

THERE are three kinds of inner *Epicycloids*; the first is when the Diameter of the generating circle is less than the semidiameter of the circle which is in the base; the second, when 'tis equal to it; and the third, when 'tis greater; we have shewn at the end of the Dimension of *Epicycloids*, that is among the interior or inner, that those that are of the first and third kind or sort, are the same; for that whose diameter of its generating circle is less than the semidiameter of the circle of the Base, is the same as that which on the contrary, the Diameter of its generating circle is greater than the semidiameter of the circle of the Base, if the circle of the base is the same, and that the generating circle of this last, have its diameter equal to the difference which is between the diameter of the Base, and the diameter of the generating circle of the first; wherefore I shall speak only here of those *Epicycloids*, whose diameter of the generating circle, is less than the semidiameter of the circle of the base. For that which is of the second kind of inner *Epicycloids*, 'tis a right line equal to the diameter of the circle of the base.

Fig. 178. Let the inner *Epicycloid* be MH , whose base is the circle ABM , and its centre in C , and let the generating circle IHA of the *Epicycloid*, be so placed on the base, that the point describing H be on the *Epicycloid*. From the centre C of the base having drawn the radius CA to the point touching A of the generating circle with the base, which passes also by the centre of the circle.

I say,

I say, that the right line I H drawn from the extreame I of the diameter of the generating circle to the describing point H, will touch the *Epicycloid* in the same point H.

Lemma 5.

Fig. 179. Let the semicircle be S T A R, whose diameter is S R, and let the circumference be divided into any number of equal parts that you please, so they be even. From the points of Division having drawn the perpendiculars to the diameter S R, and the touchings as T B which are terminated at the nearest perpendiculars which are beneath.

I say, that the sum of the touchants, as T B, without counting the first which is infinite being drawn by the point S, and the last; is greater than the circumference of the semicircle, without counting the first and the last arches of Division.

Lemma 6.

The same things being put as in the precedent *Lemma*, it may be demonstrated, that the divisions of the circle being indefinitely small, the sum of the Touchants cutting as those before, without having regard to the first and last, differ not sensibly from the circumference of the circle, leaving out the first and last arch of Division.

Lemma 7.

The same things being as before, it may be demonstrated that the sum of the parts as A B which are cut off from the perpendiculars of the Diameter of the circle, between the circumference A and that which is cut off B of the upper touchant T B, which is the nearest, may be found less than any small quantity which may be proposed, and by consequence the points as B, may be considered as on the circumference of the circle.

Lemma 8.

Fig. 180. In the circle D H B whose centre is C, and the touchant D A in D, terminating in the Radius C B A lengthened;

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ned; having divided the arch DB in two equally in H , and having drawn CHG terminated by the touchant DA .

I say, that the double of the touchant DG , or which is the same thing, that two touchants together DG , HR , touching in the points D and H , and terminating at the radiusses CG , CA , are greater than the arch DHB , but that the difference of these same touchants from the arch DHB is left less than the half of the difference between the touchant DA and the same arch DB .

But as in the continual Bisection of arches, we may demonstrate always the same thing, it follows, that we may find a sum of touchants terminated at the Radij, which pass through the points touching the next following, which will differ from the circumference of the semicircle less than any quantity proposed; and by consequence these touchants may be considered as the arches of the circle in a division indefinitely small.

Lemma 9.

The same things being as in the precedent, I say, that the sum of the portions of the Radij HG , BR , contain'd between the touchants and the circle is less than the moiety or half of the portion BA of the Radius contain'd between the circle and the touchant DA ; and for as much as this diminution which is augmented more than half, will be always by the continual bisection of Arches, 'tis evident that we may find a quantity which will be the difference of the Radij between the touchants and the circle, which will be less than any small quantity proposed; whence it follows, that in the division of the circle into indefinite small parts, the meetings of the touchants with the Radij may be consider'd as if they were on the circumference of the circle.

Lemma 10.

'Tis said in the 6th. *Lemma*, that in the divisions of a circle indefinitely small, the portions of the circumference differ not sensibly from the touchants, being lessen'd by the method proposed; and that these touchants may be taken for the arches of the circle, we may now demonstrate the same thing in the Epicycloids, and in the Cycloids.

Lemma

Lemma II.

Fig. 181. The semicircle B D A being divided into parts indefinitely small as D F, and by the points of division as F, having drawn the lines M F Z perpendicular to the diameter A B, and by the extrem B of the diameter A B, and through all those points of division as D, having drawn the right lines B D M terminating in M in the perpendiculars M F the nearest to the lowest.

I say, that the sum of all the portions, as D M of the lines B D M in the semicircle, is equal to the double of the diameter A B.

P R O P O S. III.

I Say, that the bigness of the crooked line of the outer Epicycloid is equal to the right line, which hath the same reason or proportion to the diameter of the generating circle taken 4 times, as the sum of the diameters of the two circles, to wit, of the generating, and of that of the base, to the diameter of the circle of the base.

P R O P O S. IV.

THe crooked line of the inner Epicycloid is equal to the right line, which is to 4 times the diameter of its generating circle, as the difference of the diameters of the circles of the base and of the Generatour, to the diameter of the circle of the base.

P R O P O S. V.

Fig. 182. **I**N the first place, I say, that when the Diameter of the generating circle is equal to the diameter of the circle of the base, the Epicycloid degenerates into a right line since, 'tis nothing but the diameter of the circle.

Secondly, If the diameter A B of the generating circle of the inner Epicycloid, is greater than the semidiameter C B of the circle of the base, but less than the whole diameter; I say, that the inner Epicycloid is the same as that which is described

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bed by the circle D E F, whose diameter D E is the difference between the diameter A B of the generating circle, and the diameter G B of the circle of the base, and the diameter D E will be less in this case than C B, we may find the bigness of this *Epicycloid* by the 4th. *Proposition*.

Thirdly, if the generating circle have its diameter greater than that of the circle of the base, the *Epicycloid* which will be described by the generating circle will be an outer *Epicycloid*, which will be the same as the Exterior which will be described on the same base, by another circle whose diameter is equal to the difference of the diameter of the generating circle and of that of the base.

Lemma 12.

What is said at *Lemma 11*. touching the likeness or proportion of D Q to D M towards the parts of the base of the *Epicycloid*, will be the same as for the parts above the point D.

This *Propos.* is evident, since we may make the triangles alike with the parallel lines on both sides the point D, as appears in the Figure.

Lemma 13.

Fig. 183. Let the Semicircle be A M C I, whose circumference divide into parts indefinitely small as C I, I X, from the points of division C I X having drawn the perpendiculars C B, I E, X R to the diameter A M, and the Chords A C, A I, A X, which meet with the Perpendiculars of the nearest divisions from above to the points F R.

I say, in any Segment of the circle which you please, that all the portions together of the Chords, as C F, I R, contain'd between the circumference of the circle and the upper perpendicular, are equal to the double of the Chord A C; and by the same reason all the portions taken together in the semicircle, are equal to the double of the diameter, which is also the Chord of the Semicircle.

P R O P O S. VI.

Fig. **I**N the *Epicycloid* P D, whose top is P, and any arch P D 184. **L** from its top, the generating circle B D A being put so that the describing point be in D, and that the diameter A K B in this Position tend to the Centre C of the base.

I say, that if we make it, as C A the radius of the base, is to C K composed of the Radius of the base and of the Radius of the generating circle, so the double of the Chord B D of the arch B D of the generating circle which answers to the arch P D of the *Epicycloid*, is to a fourth Proportional, that line will be equal to the arch P D of the *Epicycloid*.

Of the motion or rouling of Epicycloids, and of the Cycloid.

Lemma.

Fig. **L** E T the line DTFB be always crooked on the same 185. **L** side about which apply a flexible line; if we open or unfold part of this applied line, so that its part A B between its extreame A and the curve in B be stretcht out, then by consequence it will be a streight line.

I say, that the right line A B touches the curve or crooked in the point B, from whence it begins to extend it self.

The line described by the end A of the flexible line which is always stretcht out in its opening, is said to be described by the rouling of the curve D T F B.

P R O P O S. I.

The Line described by the rouling of an Epicycloid, is an Epicycloid.

Fig. **L** E T the *Epicycloid* be B D L, its generating circle F D E, 186. **L** its centre P, and whose circular base is A E L and the centre C, the top of the *Epicycloid* let be the point B.

If from the centre C and the Semidiameter C B we describe the circle B F M, which let be the base of the *Epicycloid* B G K, whose generating circle will be F G H, which has for its diameter F H or B I, which may be determin'd by saying, as C A is

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is to C P, so is 2 EF or 2 AB , to a fourth proportional E H or A I; and having taken from A I the diameter A B of the generating circle, there remains B I or F H, which will be the diameter sought.

I say, that the *Epicycloid* B G K is described by the Rolling of the *Epicycloid* B D L. By construction, and by the precedent Propositions of the dimension of the lines of *Epicycloids*, it appears that the Curve of the Semi *Epicycloid* B D L is equal to the right line A I or L K.

Now let the flexible line be fitted about the Semi-epicycloid B D L, of which the portion from the point D even to the top B will be extended in the right line D G; this right line D G, by the precedent *Lemma* touches the *Epicycloid* in the point D; Wherefore if we put the generating circle of the *Epicycloid* in the position F D E, or the describing point being in the point D; it is certain by the property of Touchants of *Epicycloids* that the right line D G touchant, passes through the extream F of the diameter E F, in the position F D E of the generating circle.

Having prolonged C E F to H in the circle I H K concentric in the circle of the Base, which is described on the Semidiameter C I; on F H for a diameter describe the Semicircle F g H. I have demonstrated that the extream G of the flexible line stretcht out from the point D, will be on the circle F g H.

If the point G is not on the circle F g H, and the right line D F G meet, if it may be the circle F g H in any point g; then draw H g; because of the Semicircle F g H, the angle F g H is right, and the rectangled Triangles E D F, F g H will be like, because of the equal angle at the point F. Wherefore E F will be to F H, as F D to F g; and being compounded, E F will be to E F more F H, that is E H, as D F to D F more F g, that is D g; and by doubling the Antecedents 2 EF or 2 AB , they will be to E H or A I, as 2 FD to D g.

By *Propos.* the 6th. of the dimension of *Epicycloids*, and by construction; as 2 AB are to A I, so C A is to C P: But as C A is to C P, so is the double of the Chord D F to the bigness or Magnitude of the portion D B of the *Epicycloid*, which portion by the rolling is equal to the right line D G: Wherefore by equal reason 2 AB are to A I, as 2 DF are to D G. But I come to demonstrate that 2 AB are to A I, as 2

FD are to Dg ; then $2 FD$ are to DG , as $2 FD$ are to Dg , and by consequent DG will be equal to Dg : then the point g of meeting of the right line DFG , and of the circle FgH , will be the extreame G of that line.

It remains now to demonstrate that the point G is in the *Epicycloid* BK , whose generating circle is FGH . By construction CA , is to CP , as $2 AB$ are to AI ; by dividing, CA is to CP less CA that is AP , as $2 AB$ to AI less $2 AB$; but by doubling the Consequents, CA is to $2 AP$ which is equal to AB , as to $2 AB$ to $2 AI$ less $4 AB$; and by compounding, CA is to CA more AB that is CB , as $2 AB$ to $2 AI$ less $4 AB$ more $2 AB$, that is $2 AI$ less $2 AB$, or only $2 BI$, as it appears in the figure.

But in taking the half of the Terms of the last proportion CA is to CB , as AB to BI : But also as CA is to CB , so is the length of the arch AE to the length of the arch BF .

Now by the generation of the *Epicycloid* BDL , the arch of the base AE is equal in length to the arch of the generating circle FD ; but because that the two circles FDE FGH touch each other in F , the line DFG cuts the two arches alike FD , FG , whose lengths keep between themselves the same ratio or proportion as those of the Chords FD , FG , or those of the diameters FE , FH : Then the arch FD is to the arch FG , as FE to FH ; or as AB to BI , which is also as CA to CB , or as the arch AE to the arch BF : But the arch AE is equal to the arch FD ; then the arch BF is equal to the arch FG of the circle FGH , and by consequence the point G is that which describes the *Epicycloid* BGK ; which was to be demonstrated.

For the inner *Epicycloids* we may demonstrate the same thing, only changing the form of the proportion: And for the *Cycloid* 'tis easy to behold by the same demonstration, that the line which is described by its roling, is the *Cycloid* equal to that which is roled.

Corollary I.

Hence it follows also by *Hypothesis* that the 3 lines CA , CB CI are continual proportionals: For CA is to CP as two AB to AI , in dividing and doubling the Consequents, CA will be to $2 CP$ less $2 CA$, as $2 AB$ to $2 AI$ less $4 AB$: But $2 CP$ less $2 CA$ are equal to $2 AP$ or to AB ; and as $2 AB$ to $2 AI$ less $4 AB$, so AB to AI less $2 AB$; wherefore CA is

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to A B as A B to A I less 2 A B: But in compounding, C A is to C A more A B which is equal to C B, as A B to A B more A I less 2 A B, which is equal to B I; and by Altern proportion C A is to A B, as C B to B I; lastly, being Compounded C A is to C A more A B which is equal to C B, as C B to C B more B I which is equal to C I.

Corollary 2.

'Tis evident as yet that the line which is described by the roling of a circle, is the last of all the outer *Epicycloids*, that is to say, that whose centre of the generating circle is at an infinite distance; or that which is described by the end of a right line which roles about a circle in the Touchant, which doth agree with the roling of the circle.

'Tis easy to demonstrate that the superficies of the figure of this kind of *Epicycloid*, when the describing line runs over the whole circle of the base, or that it comes again to the same thing; The figure described by the roling of the whole circle, without comprehending the circle which makes the roling, is equal to one third of the circle, which hath for Radius the circumference of the circle of which the roling is made. What I say of the whole circle, the same is intended of every part of this Figure. For the figure described by the roling of any arch of a circle, without comprehending any thing of that circle, is equal to $\frac{1}{3}$ of the Sector of a circle, which has for Radius the circumference of that arch, and of which the arch is like to that of which the roling is made; It will be also the same thing for the roling of a greater arch, and of the whole circle. For that which is the crooked line of this *Epicycloid*, or of that which is described by the roling of an whole circle or of any arch, which shall be always equal to half of the circumference of the circle or of the arch of which we take $\frac{1}{3}$ of the superficie, for the superficie of the Figure described by the roling,

P R O P O S. I.

Of the use or advantage of Epicycloids in Mechanicks.

Fig. 187. **L**ET the right line A D be a determined length, and movable on a Plane about its extream A; and on the same plane let there be another right line C B, indeterminate towards.

towards B, and movable on the plane about its extreame C: if the Extreame D of the line A D is led into E and R, by the line C B, which moves it self on the point C.

I say, that if the lines A D, C B, be placed on the line C A which joins the Centers of movement, and the points D and B be put one upon another, there will be two powers equal between themselves, which will act with all their force on their lines in the points D and B, that is to say, (with direction at right angles) these powers will be in *Equilibrio*; but if the lines change their position, as A D into A E, and C B into C B E, the Powers equal to X being applied always in the same manner to their lines, and to the same places, they will be no more in *Equilibrio*, but to make them in *Equilibrio*, we must have another power Y greater than X applied in B, on C E, and this Power Y ought to be so much greater, as the line C B E is removed from C A.

From the centre C and Semidiameter C D or C B, having described the circle B B, 'tis evident that C E is greater than C B. But from the point E having drawn E G perpendicular to A E, and E F M perpendicular to C E, and by the point A having also drawn H A M parallel to C E, if from any point F of the line E F we draw the line F G parallel to C E, the two triangles F E G, M E A will be alike, for they are rectangled, and their angles in the point E are equally together to a right angle, because of the right angle A E G.

If we suppose now the part E F indefinitely small, 'tis evident that the line C E cannot be moved from E to F about the point C, without causing A E to move to G about the point A. But it follows from the Laws of *Mechanicks*, that to make an *Equilibrio* between the power X applied to the extreame or end E of the lever A E, which moves according as the line E G, and between the power Z applied to the end E of the lever C E, which moves according to the line E F; it is necessary that X be to Z as E F to E G, that is to say, as A M to A E: In fine, if we suppose the power Y applied to B on the lever C E in the point B, 'tis evident, that to make an *Equilibrio* between Z and Y, it is necessary that Z be to Y, as C B to C E: It follows therefore, that for to make an *Equilibrio* between X applied to E on the end of the lever A E, and Y applied in B on the lever C E, it must be that X must be to Y in the compound proportion, of A M to A E, and of C B

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to CE , which is the same as that of the rectangle AM , CB , to the rectangle AE , CE . But in the rectangle triangle AME , the side AM will be always lesser than the Hypotenuse AE ; and by construction CB will be also always lesser than CE , whence it follows, that the power Y will always be greater than the power X , and that the more the lines CE , AE are removed from the line AC which joins the centres of the movement, the more the power Y ought to be greater for to make *Equilibrium* with the power X .

Fig. 187. We may likewise demonstrate the same thing after another manner, in keeping to the common principle of the ballance, or leaver. For if on MA lengthned, we take AH equal to AE , and consider CE and MAH as two horizontal Leavers, the points of whose props are in C and in A , and that the end E of the leaver CE have a weight called Z , this weight will have the same endeavour on the point E of the elbow leaver $HA E$, as on the point M of the right leaver or ballance $H A M$. For 'tis evident, that the weight X in the point H , will be to the weight Z , as AM to AH , or AE its equal. But now if instead of the weight Z applied in E on the end of CE , we substitute a weight Y applied to the point B of the same leaver CE , for to make the same endeavour as Z in E , it will be, that Y will be to Z , as CE to CB : Then the weight X will be to the weight Y for to make an *Equilibrium* in the compounded proportion of AM to AE , and of CB to CE , as before, whence follows what was proposed.

Corollary.

It follows from this demonstration that a power applied in B to the end of the Leaver CB , will not act equally against another power applied in D to the end of the line AD in the meeting of its extreame D , when these lines are differently posited, their powers will always be applied in the same points of their lines CB , AD , and they will act perpendicularly; But then one must be so much greater as the line CB is more removed from CA .

If you intend the contrary, the power which acts must be applied to the end D of the line AD ; for this force or power ought to be less when the line AD is more removed from AC , than when 'tis nearer.

PROPOS.

P R O P O S. II.

Fig. 187, **T**He same things being put as in the precedent,
 188. I say, that if on the circumference of the circle $B B$ as a base, we describe the Epicycloid $B H$, whose generating circle is $D E R$, and Radius the line $A D$, the crooked line of this Epicycloid being join'd to the Radius $C D$ of the base, and not making with it the same mixt line, as in the position where it was described, in any place which $C B$ is placed out of $C A$; and the end D of the line $A D$, being put on the Epicycloid in E , the power Z which is applied in E , at the end of $A E$, as 'tis in the precedent proposition, will be in Equilibrio with the same power Z , which is applied in B to the end B of the line $C B$, and which acts on the point E by means of the curve of the Epicycloid $B E$.

Fig. 188. 'Tis easy to see in this figure by the forming of the Epicycloid, that in any position, which the line $C B$ is in, which is joined to the Epicycloid, the Arches $B B$ will be always equal in length to the arches $D E$ of the circle $D E R$; wherefore let $C B$ be in any place, and the power applied in B cannot move it self through one arch $B B$, without moving the other force applied in E on the end of the leaver $A E$, by an arch $E E$ equal in length to the arch $B B$; whence it follows, that the powers being equal they will remain in Equilibrio; which was to be demonstrated.

Fig. 189. We may also make this Demonstration as in the precedent proposition; and we shall find that the same method which is managed in the inequality of powers, will lead us here to equality by compounded Reason: For if we suppose that the end E of the leaver $A E$ hath the power $X A$, which acts according as $E G$ perpendicular to $A E$, and that in the point E at the end of $C E$, there be a power V which acts according as $E F$ perpendicular to $C E$; 'tis evident by the nature of the Epicycloid, that the line $N E$ drawn by the end N of the diameter $D A N$ to the point E , will touch the Epicycloid in that point; and that as when the point E of the end of the leaver $C E$ shall have run over a space $E F$ indefinitely small, the same point E of the end of the leaver $A E$ will be come to G , where the line $F G$, parallel to $E N$, meets $E G$ perpendicular to $A E$; for the small portion $F G$ of the Touch-
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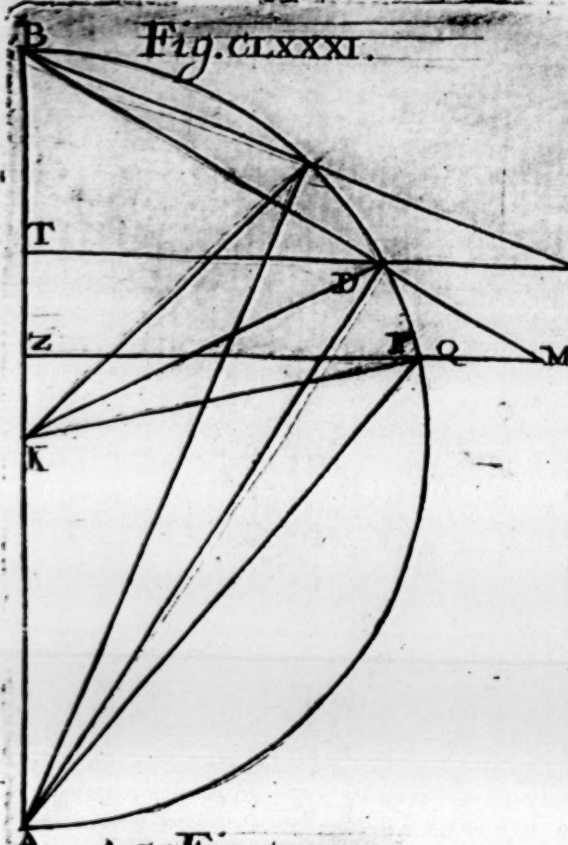


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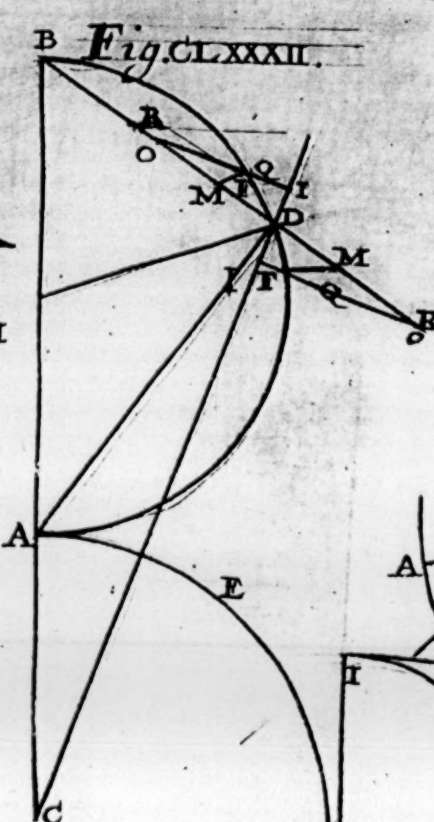


Fig. CLXXXII.

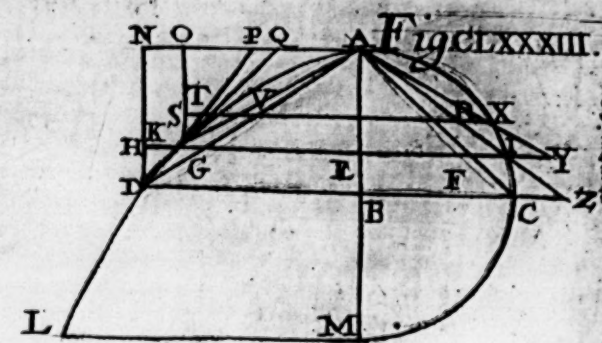


Fig. CLXXXIII.



Fig. CLXXXV.

Fig. CLXXXVI.

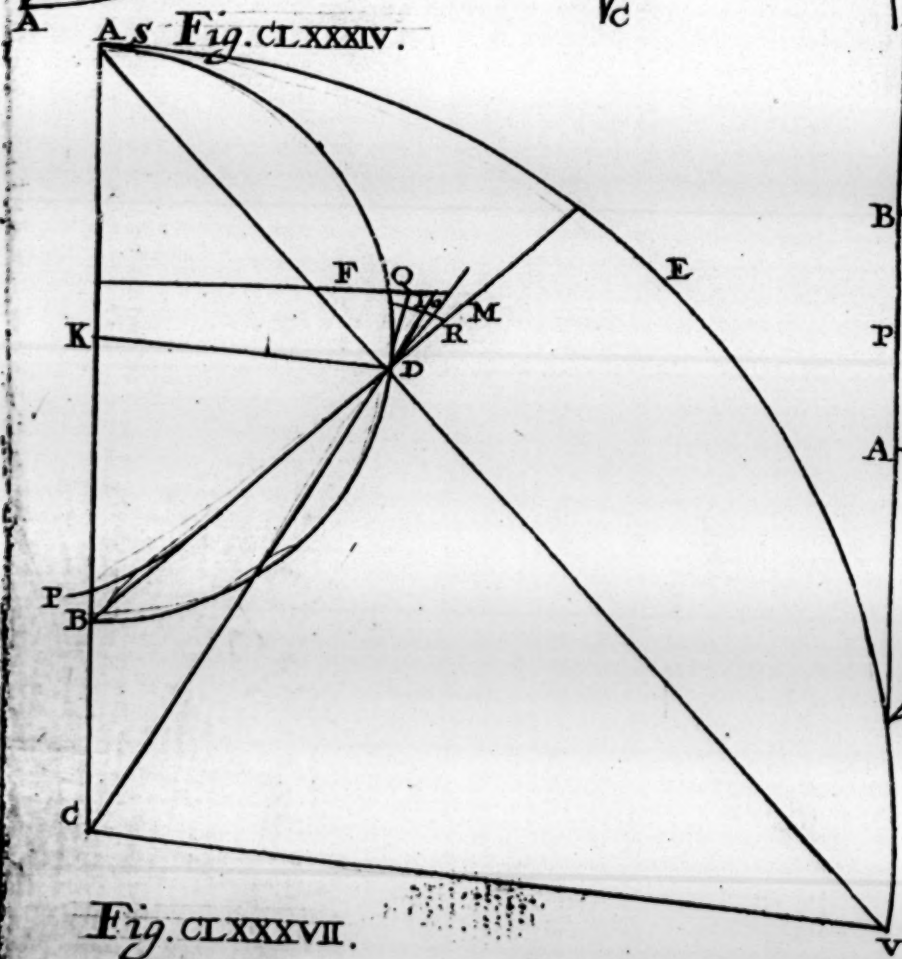


Fig. CLXXXIV.

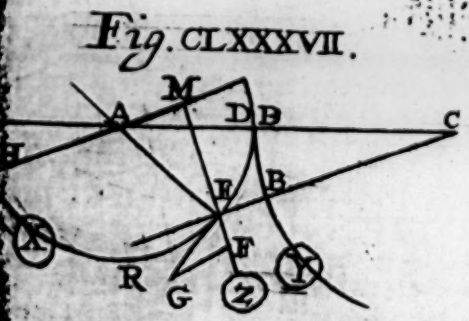
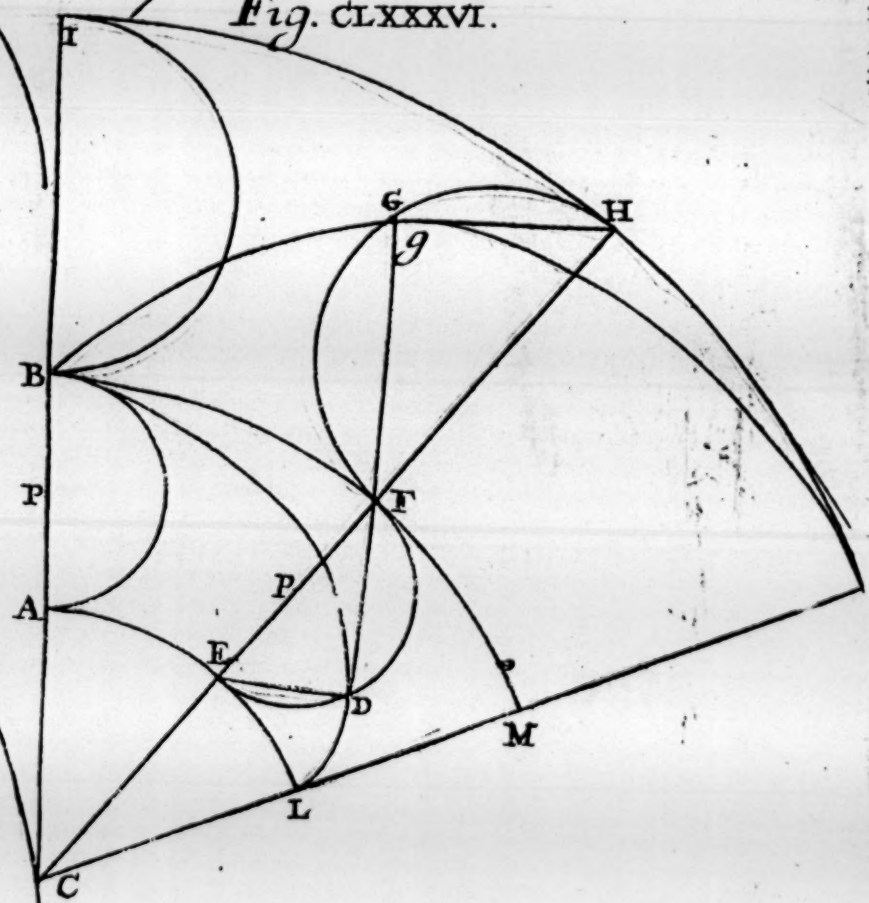


Fig. CLXXXVII.

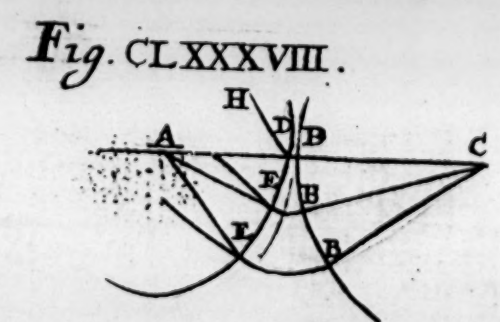


Fig. CLXXXVIII.

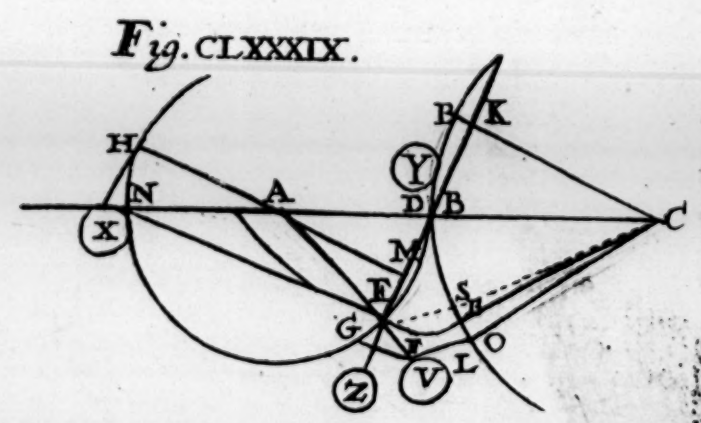


Fig. CLXXXIX.



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ant $E N$ may be considered as the same curve. But having drawn $F C$ which meets the circle $B B$ in L , the arch $S L$ of the circle $B B$ between $C E$ and $C F$, will be equal in length to $E G$ by the nature of the Epicycloid; for when the point E of the Epicycloid shall be come to G , the beginning of the Epicycloid B on the circumference of the circle $B B$ will become to O ; so that the arch $B O$ will be equal to $S L$.

The Power X runs over then the space $E G$, when the power V runs over $E F$, and for to make an Equilibrium between these two powers, it must be, that Z must be to V , as $E F$ to $E G$, that is to say, in reciprocal reason of the spaces run over. But lastly, if we suppose the power Y in the point S , or in the point B , on the circumference of the circle $B B$, and that it makes Equilibrium with the power V , it will come to pass that V will be to Y , as $C B$ to $C E$; then the power X will be to the power Y , in the compound reason of $E F$ to $E G$, which is the same as $E F$ to $S L$, or that of $C E$ to $C S$ or $C B$, and of $C B$ to $C E$. But this compounded reason is a reason of Equality, wherefore the powers X and Y ought to be equal for to make Equilibrium between themselves, being applied, as we suppose, which was to be demonstrated.

Corollary.

That which I come to demonstrate of the Epicycloid described on the circle $B B$, for its base and for its generating circle $D E$, whose Radius is $A D$, the meaning is the same, if the Epicycloid be described on the circle $D E$ for the base, and that the generating circle be the circle $B B$, and its Radius $C B$; for the movement or motion will be always equal from one side or tother.

P R O P O S. III.

How to make the Application of motion equal to Engins.

Fig. 190. **L** Et there be a circle $B O L$ whose centre is C , and another circle $D E F$ whose centre is A : On the circle $B O L$, as a base, and for a generating circle $D E F$, describe the Epicycloid $B V H$, and divide the circumference of the circle $B O L$ into any number of parts, as here

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into eight in the points B K L, &c. and to each of these points apply a portion of the Epicycloid B V H, in K I, L M, which will be the same as if the Epicycloid had been described, beginning in the points K L, &c.

We may likewise take as great a portion of the Epicycloid as we please, as B V H, and by this means make the divisions of the circle lesser or fewer. The figure B V H G may be the tooth of a wheel which may be limited by the right line H G, which tends to the centre C of the circle, or by any other line as you please, which is indifferent, since this part of the tooth doth not cause any effect. We may also hew a little the space between two teeth, as D N O, to give the more liberty to the meeting of the parts of the other wheel D E F.

We may then form a wheel on the model of a circle with its teeth, and make it move on the centre C.

Now if we apply another wheel to the hinder part of it, whose centre is in the point A in the Horizontal line A C, and that instead of teeth, on the circumference D E F, we apply only in this example the pegs or pins of wood D E F, &c. which we suppose indefinitely small and perpendicular to the plane of the wheel; 'Tis certain by the precedent proposition, that in any position that we place the wheel B O L whose teeth meet the pins of the other wheel D E F, they will be in Equilibrium, if the moving forces applied to the Circumferences of the two wheels be equal between themselves.

Let then for this effect a weight Q be hung from the circumference of the wheel B O L, equal to the weight R, hung and applied to the circumference of the wheel D E; these two weights will then abide always in Equilibrium in any manner that the teeth of the wheel B O L meet the pins of the wheel D E F.

But if we apply a weight P to the circumference of another wheel S T, which hath its centre common with that of the wheel B O L, and which is fastned with it, this weight P will be to the weight Q, as C B to C S, the weight P will be still in Equilibrium with the weight R, in all the different meetings of the two wheels; for the weight P making Equilibrium with the weight Q, it will also be in Equilibrium with the weight R.

P R O P O S. IV.

THings being disposed as in the precedent, I say, it matters not whether the divisions of the wheel B K L be equal between themselves, that is to say, that the teeth be equally distant one to another, nor the pegs D E F on the circumference of their wheel.

It matters not whether it have one or more teeth of the wheel B K L, which act all together on the pins of the wheel D E F, for there will be no more but the same force which will be applied against that of the wheel D E F. If it have but one, as B V H, all the force of the weight P, will act against that of the weight R, in meeting with the peg D.

Fig. 190. If you would have two together, as B V H and K I, of which the first acts on the peg D, and the other on the peg E, 'tis evident by the construction of these teeth, that K I will have as much force or power on the peg E against the weight R, as B V H on the peg D against the same weight R; and by consequence the force of the weight P distributes it self equally to these two teeth, each of which counter-balance the moiety of the weight R: It will be the same thing, if you have three or more which act all together.

Thus it matters not if you have one or more teeth which work all together, and 'tis indifferent what part of the tooth meets the peg against which it acts, since it will have always the same force; which was to be demonstrated.

P R O P O S. V.

THe Engin being disposed, as before, for to make an *Equilibrium*, between the two weights P and R; I say, that if you augment the moving force of the wheel B K L; or, which is the same thing, if you add some weight Z to the weight P, this force, or this new weight will act equally in all the different encountrings or meetings of the toothed wheel E K L with D E F, on the force, or on the power; or lastly, on the weight R applied to the wheel D E F.

Since to make an *Equilibrium* between the weight P, augmented by the weight Z, and the weight R, you must augment the weight R with the weight Y, which must be to

the weight Z (which makes the augmentation of the weight P) as C S to C B, and then the two weights R and Y together will make through all an *Equilibrium* with the two weights P and Z together ; 'tis evident, that in any position which these two wheels are in, the weight Z will be always in *Equilibrio* against the weight Y ; and by consequence the two weights P and Z together prevail always with the same force against the one weight R, which is measured by the weight Y, since it wants this weight to make the *Equilibrium*; which was to be demonstrated.

P R O P O S. 6.

WE may place the Superficie of two Wheels in the same Plane, and instead of the pegs or pins which should be fastned on the Wheel D E F, we may make the teeth at the end of this Wheel, and give them what Figure we please: But then the teeth of the other Wheel whose figure will be in the *Epicycloid*, ought to have a figure composed of those of the *Epicycloid* and those of the teeth proposed, this compounded figure forms it self, as I shall explain in the following Examples.

Example 1.

Fig. 191. The most simple of all Figures is the Circular; wherefore I propose at first sight the figure of the teeth of the Wheel B E F in a circle. Let the wheel be B E F, whose centre is in A, which hath its teeth of a circular Figure, as B O P, and whose centres will be on the circle D G M, which hath its centre common with those of the Wheel A; let the centre of the other Wheel be C; having drawn the right line C A which joins the centers of the two Wheels, and which meets with the circle B E F in B, from the centre C, and with the Radius C D describe the circle D I, on which as a base make the *Epicycloid* D V H, which hath D G M for its generaing circle. Now if from all the points D V H, of the *Epicycloid*, as Centers you describe the circles O N L equal to the circle which forms the teeth of the Wheel B E F, the crooked line O N L which touches all the circles, and which will be Parallel to the *Epicycloid*, will form the figure of the teeth of the Wheel B K, that is to say, that part of the tooth which acts against the part of the circular tooth which it meets in its motion, for to the other parts of the teeth which it meets not with, I have already said that they may be made.

made of what Figure you please; but you ought always to make choice of those which are most durable, and most proper to resist the force of the motion.

I say now, if you apply equal powers to these Wheels within the distances of their centers $C D$, $A D$, in any place that the teeth meet, you will have an *Equilibrium* every where; only it must be observed that the meetings of these Teeth must be always under the line $A C$.

By the 3^d. Proposition in any place that the *Epicycloid* $D V H$ is applied to the point D of the Wheel $D G M$, in making it move about the Centre A , it will make an *Equilibrium* between the equal Powers. For if one of the powers cause the other to move, it will cause it to run over a space equal to that which the same runs over it self. But by construction of the tooth $O N L$, we see that the crooked line $O N L$ meeting the circle $B z P$ makes the point D so much advance, as if the *Epicycloid* $D V H$ met it: For the distance between the *Epicycloid* $D V H$, and the crooked line $O N L$ is every where, that of the Semidiameter of the Circular tooth $B z P$.

For example, when the centre of the tooth D is come to G , and that the *Epicycloid* $D V H$ is placed in $I G$, its point G being joyn'd to the centre of the circular tooth, 'tis evident that the arch $D I$ of the circle of the base will be equal in length to the arch $D G$ of the generating circle $D G M$; But then the crooked line $O N L$ will be placed in $o n l$, and the circular tooth $E n p$ which hath its centre in G , will necessarily touch in the point n , the crooked line or curve $o n l$, for the shortest distance, from the point G of the *Epicycloid* to the curve $o n l$ will be in the point touchant n of the circle $E n p$, and of the curve. So when the point D of the *Epicycloid* is come to I , the point O of the curve will be come to o , the arch $O o$ will be equal to the arch $D I$, and the curve $o n l$ which meets the circular tooth in n , will be made to advance its centre in G on the *Epicycloid* $I D$, and by consequence the arch $D G$ will be equal in length to the arch $O o$, or $D I$.

I have said that the teeth ought not to begin to meet or encounter themselves but underneath the line $A C$, that is to say, that the bending $O N L$ is not proper for to act on the circular teeth, but when the point O of the curve $O N L$ is come to D ; and by consequence this curve $O N L$ begins not to act against the curve or bending of the circular tooth, but in the point.

point Z, where it is cut by the circle D G M, and it continues always in the Rencounter or meeting in its part Z P, in descending beneath the line A C. We may then lessen all the part Z B of the circular tooth, since 'tis not useful in the movement, or motion, and finish it on the circle Z D. We may also finish the teeth of the other Wheel by the curve L N O, and by the circle O D, which will be the ground of the teeth; But in this construction we ought to distribute the teeth after such manner in each Wheel that they begin to rencounter or meet one another only in the line A C, and that they do not hinder one another above, which will always be easy to do.

Also note, that the curve L N O Parallel to the *Epicycloid*, begins always out of the circle O D I, and afterwards that it is between, or within; and lastly, that the diameter of the generating circle is greater than D B, which is easy to demonstrate by the generation of the *Epicycloid*; but I consider not in this place but the part O N L of this curve which is without the circle O D I when 'tis in this kind.

We ought always to avoid in the teeth of Wheels to make them work above the line A C which joins their centers, because the wearing or rubbing in them is very great, and that on the contrary 'tis not almost considerable in them below, supposing that the motion of the Wheels will be from above to beneath the line A C. In the mean time if you would that the teeth of these Wheels work in rencounting themselves above A C, it must be in the making, as I shall shew by and by, after I have shewn a general method for making the teeth of one Wheel in different manners, those of the other being always given the same.

Example 2.

Fig. 192. Instead of the Centre D of the circular tooth proposed, as in the precedent example, I take another point like that where I please, as B on this tooth, and by means of this point I find the figure of the tooth B N N, which ought to work with the proposed; but for to cause the tooth proposed to act or work in as many parts as is possible, we ought to chuse a point in this tooth which may be the nearest to the Centre C of the other Wheel, in the motion of this point
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chosen about the center A of the Wheel unto which 'tis fastened, and this point will be the point B in this Example.

From the centre C and with the Radius CB describe the circle B K, which will be the base of the *Epicycloid* B V V, whose generating circle is B G G described from the centre C and Radius A B; then from the centre A having drawn the Radius A G, from the centre C, and by the Radius C G we may describe the circles G V, which cut the *Epicycloid* in V, and by these points V we may draw the lines V H I, which make the angles C V I equal to the angles C G A. Then on the lines V H I we may apply the figure B z of the tooth proposed in the same manner as 'tis applied to the line A B, in making it agreeable in the point B or V, and we may draw the curve line B N N that shall touch the curvature or bending of the proposed tooth, in all these different Positions, which same thing will happen for the circle, if we take on V H the Magnitudes V H equal to B D the radius of the circle of the proposed tooth, and that from the points H for a center we describe the circles N equal to those of the tooth.

It plainly appears by this formation of the curve B N N that in any position that it meets the circular tooth, the point B of the curve B N N being beneath A C, there will be every where an *Equilibrium* between 2 equal Powers applied to these Wheels in the distances C B, A B, from their centers C A: For we may demonstrate, as in the preceeding example, that in any position that the curve B N N is applied to the circular tooth, it will be disposed to make its way in the point B on the circle B G, a space equal to that which the same point B makes on the circle B K. For example, if the point B in running over the space B K on the circle B K, the same point B comes to G, by means of the *Epicycloid* B V, which must be placed in K n, but the curve B N N will be placed in K n, and its point N will be applied in the point n, of the circular tooth B Z, transported in G n, which will have its center in b on A G, and by consequence the curve K n, which acts on the circular tooth G n in the point n, makes the point G to advance, so much, as if the *Epicycloid* should be placed in K G, and joined to the curve K n.

'Tis easily seen, that if the tooth of the Wheel B K is formed as the curve B N N, it will begin to act on the circular tooth B Z, in the point B on the line A C: For so soon as the point

B of the curve B N N is come to A C, and that it touches the point B of the circular tooth, the 2 teeth begin to act one against the other, and to measure how much the tooth B N N descends its different points N, as they are applied in different places of the circular tooth B Z.

Note, that if we take the lines V H I equal to B A, all the points I will be in the circumference of the circle A I I, whose center is in C; and moreover, that all these points I will be the Centers of the generating circle of the *Epicycloid*, in the different positions whence it describes the points V.

Lastly, we may take the point B for the Commencement of the *Epicycloid* in what place you please, whether within or without the tooth, instead of taking it in B on the curve of the proposed tooth, as is done in this example, and we may find always a curve for the tooth which ought to work with those proposed, and which ought to make an *Equilibrium* between two equal Powers, which I shall explain in the following Examples.

Example. 3.

Let the right lined tooth be Z D, which makes with the Radius A Z the angle A Z D, and let the point be D of this tooth which ought to begin to work with the tooth of the other Wheel B K; having taken any point B in the line A D C which joins the centers, and which passes through the point D, determining to what place the tooth A Z D should be made to move on its center A; or if the point D be not determin'd on the tooth Z D, and that there be given the point B of like position to the line Z D, or to the angle A Z D, having drawn A B which cuts Z D in D, we may place the line A B on the line A C, and describe the circle B K from the center C, and the Radius C B; this circle will be the base of the *Epicycloid* B H M, of which the generating circle is B G, described from the center A on the Radius A B.

Then to all the points G of the circle B G, having drawn the Radius's A G, and from the Center C, and for the Radij C G having described the arches of the circle G V, which encounter in V the *Epicycloid* B V M, I draw C V, and afterward V H I, which makes the angle C V I equal to the angle C G A; on V I, I apply the line H Z in the same manner that

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DZ is applied to BDA, that is to say, that VH is taken equal to BD, and that the angle VHZ, is equal to the angle BDZ, the lines HZ will intersect them all, whence we may draw the curve-line DN which will touch them, this line DN will be the figure of the tooth which we seek, and which ought to be applied to the wheel BK.

'Tis evident by what is demonstrated before of the formation of the second teeth on the first which are given, that the curve DN of the tooth applied to the wheel BK meeting the right lined tooth DZ below the line AC, and beginning in the point D will make every way an Equilibrium between 2 equal powers applied to the 2 wheels in the distances of CB and AB, that is to say, in the extreame of their Radij; for if we suppose that the line CB have transported the point B to K, the Epicycloid BVM will be placed in KG, and the line AB will be placed in AG, so that the arch BG will be equal in length to the arch BK by the property of the Epicycloid. But then in this position, the tooth will be in ASD, and the curve DN being put in En, its point n which is the same as the point N, will touch the tooth in n; and even as in all the points as G and K the motion will be equal, there will be every way an Equilibrium between the two equal powers.

Where Note, That we ought not to determine the length of the right lined face ZD of the tooth towards D; for it may happen in some cases that the curve DN may not be touchant to all the lines, as HZ, for these lines HZ intersect not, their extreame H being determined and they rencounter not the next; and if we should draw the curve line DNN through all the points as H, it would happen that only the end or extreame D of the tooth would work, and would notwithstanding make the motion equal, but this is not that which is proposed in this place.

Example 4.

Fig. 194. We may yet make another sort of right lined tooth, the face of which tends to the center of its wheel, and by this means the tooth which acts against it, has not its face inclined to the circle on which it is fastned, as in the preceeding

Examples, and this kind of tooth is one of the easiest to execute in great Engines, and most useful for the motion.

Let the face be $F D$ of this right lined tooth which tends to the center A of its wheel, and which is placed in the line $A B C$ which joins the centers of the wheels. By any point B of the line $A C$, and from the center C , describe the circle $B K$ which is the base of the Epicycloid $B V$, whose generating circle is $B G$, described from the center A and the Radius $A B$; having drawn all the Radij $A G$, and the lines $C G$ which are the Radij of the circles $G V$ which rencounter the Epicycloid in V , whence the angle $C V I$ will be made equal to the angle $C G A$. Lastly, whence we may draw the curve $D N N$ which will touch all the lines $V I$ in their different positions, and which will be the figure of the tooth which ought to be applied to the wheel $B K$. This tooth $D N N$ rencounters the face $F D$ in all its different positions, and will make every way an Equilibrium between 2 equal powers applied to their wheels in the distances of $C B$ and $A B$. For the curve $D N N$ being placed in $d n$, which is fastned to the Radius $C K$ and rencounters the face $A F D$ of the tooth proposed in n in the position $A G$, will make the same effect on the point G , as the Epicycloid $D V$ placed in $K G$, as I have made appear in the preceeding example.

'Tis easy to behold by what is explained before, that it will not be difficult to form the tooth which we seek, that which is given being of another figure than the circular or right lined, as Parabolique, Hyperbolic, and the same in the Epicycloid.

P R O P O S. VII.

ONe may describe an Epicycloid on a base which is concentrick to the wheel which carries the proposed tooth, and by means of this Epicycloid, we may find the Figure of the second tooth, as in the preceeding proposition.

Fig. 195. Let $Z D$ be the figure of the tooth proposed which is applied to the wheel Z , the center whereof is A ; and on this first tooth mark the point D , which ought to begin to work or act with the second tooth that we ought to apply to the other wheel, place the tooth $Z D$ in making it turn with

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with its wheel about the center A, so that its point D be on the line A C, which joins the centers of the 2 wheels; in this position of the tooth Z D, having markt any point B that you please on the line A C, from the center A, and with the Radius A B describe the circle B G, which will be the base of the Epicycloid B V, whose generating circle is B K, described from the center C and Radius C B.

'Tis evident by what is demonstrated before, that the Epicycloid B V being fastned to the Radius A B, will so much advance the point B from the Radius C B, as the same point B advances on the circle B G in any position that the Epicycloid shall be, as if it is transported to G K, the arch B K will be equal in length to the arch B G, and so the difference being every way the same of these arches, they will also be equal in length, in manner as if the Epicycloid is placed in G K, the point G will not advance any space, but will be on its arch B G, and it makes not so much to advance the point K on the arch B K.

Now to all those points K of the circle B K, having drawn the Radij C K, and afterwards A K, and from the center A and Radius A K, having described the arch K V which cuts the Epicycloid in V, and the line A C in F, whence the arch K L will be equal to the arch V F, and then drawing L A which will cut the arch B G in G, whence 'tis evident, that the portion B V of the Epicycloid may be accommodated in G K.

Having made the angle C B I equal to the angle C K A, and B I being equal to K A, whence also the angle B I g will be equal to the angle K A G, and on g I equal to A B, or to A G, if we apply the curve E N Z of the tooth given D Z, in the same manner that it is applied on B A, as if we transport it so that the point B be put or placed in g, and the point D in E.

Lastly, the Curve of the proposed tooth in all its different positions will form another curve N N D by a line which will touch them all, which will be the figure of the second tooth which we seek, and which ought to be applied to the wheel B K, or to the radius C B D in the manner which 'tis described.

'Tis evident, that this curve N N D will so much advance the point B on its arch B G, as the same point B advances on B K: For when the point B is placed in K, the curve N D will advance the tooth Z D in S n d, for the point n of this

curve which rencounters the tooth in the position $S n d$, rencounters it in the same manner, and in the same place as the point N which it forms. So the *Epicycloid* will be in the position $G K$, and by consequence two equal powers being applied to these two wheels in the distances of their Radii $A B$, $C B$, will act every way equally, and will make an *Equilibrium* in all the Rencounters of the teeth of the two wheels.

P R O P O S. VIII.

To apply a little Wheel instead of a Tooth to the Wheel of an Engin.

Fig. I Have noted in the 6th. Proposition, That the second 196. **I** Tooth ought not to begin to work with the first, but on the line $A C$; because that the wheels having their motion above or below this line, the faces of the Teeth which rencounter themselves in their removing one from another, do only rub one another in making their escape, which causes not any sensible hinderance to the motion; whereas when the rubbing is made by the rencountering of the parts which venter or come upon one another, the Impediment to the motion is very considerable, and is that which we chiefly ought to avoid in Machines and Engines.

Behold here a particular construction for the Teeth of Wheels of a great Engin, where the faces which rencounter themselves or meet, are made so that they touch one another without rubbing or wearing, and what remains is only made on the Axis, or Pivot:

The construction of these Teeth is the same as those of the first Example of the 6th. Proposition, but the Application is different: In the 6th. Proposition the circular Tooth proposed is stayed firmly by the Wheel; but in those here that is a little wheel which is movable about its centre D , on an axle-tree, or pin, placed at the end of the Radius $A D$; there will be then no other fretting; or wearing, in this Engin, than that of the little wheel $B Z P$ on its axis; for the circumference will apply it self every way, without fretting, or wearing, on the Curve of the other Tooth $O N L$.

Fig. CXC.

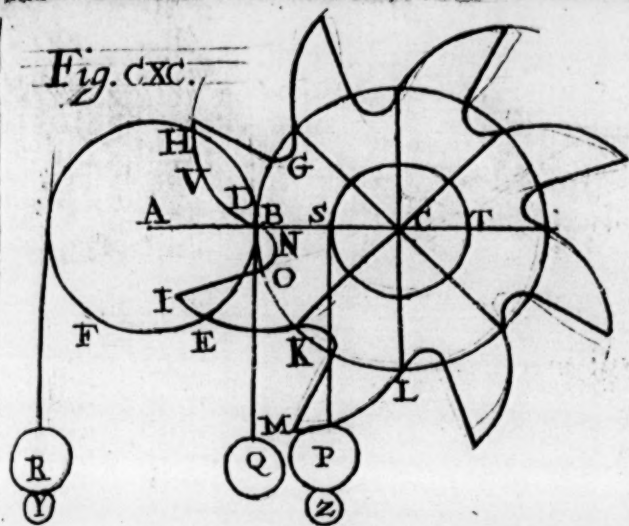


Fig. CXCL.

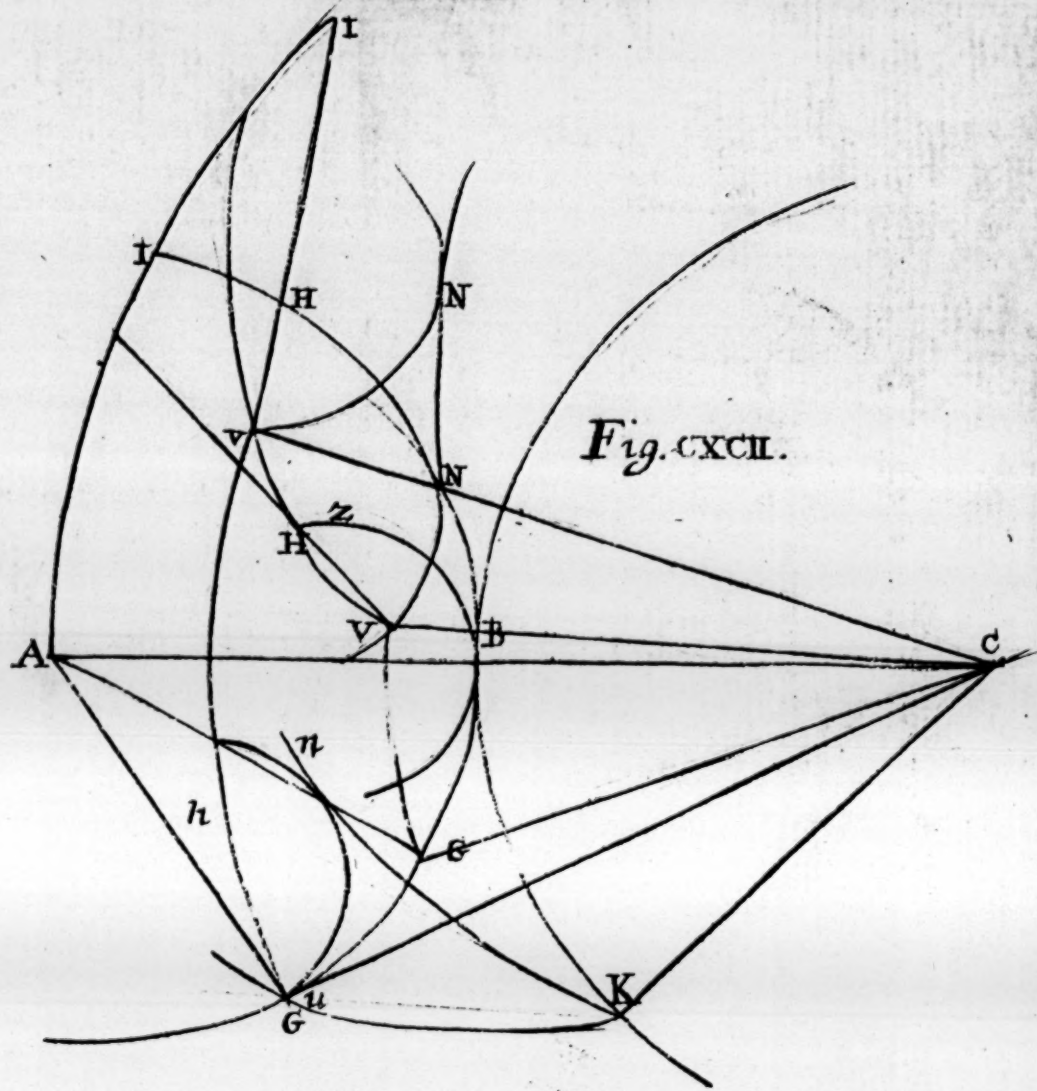


Fig. CXCI.

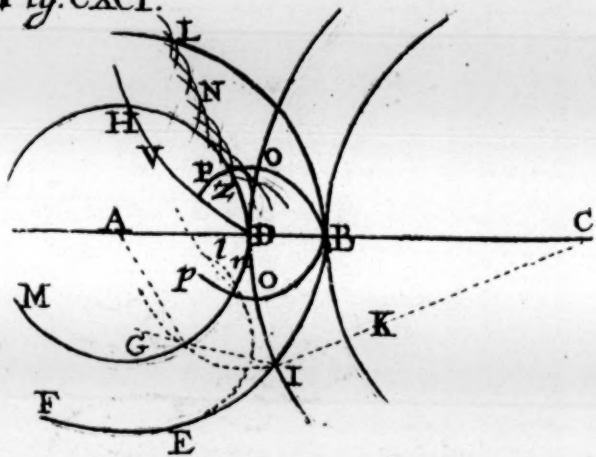


Fig. CXCVI.

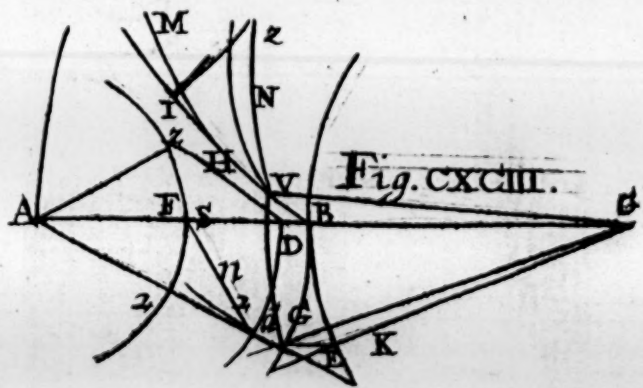


Fig. CXCVII.

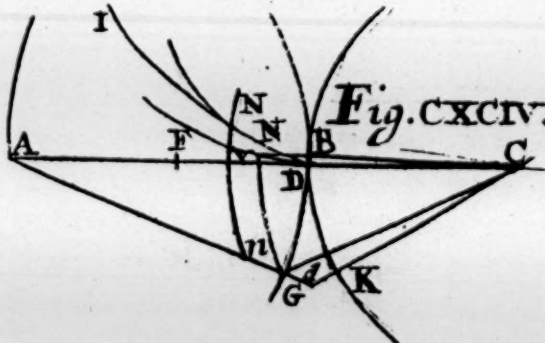


Fig. CXCVIII.

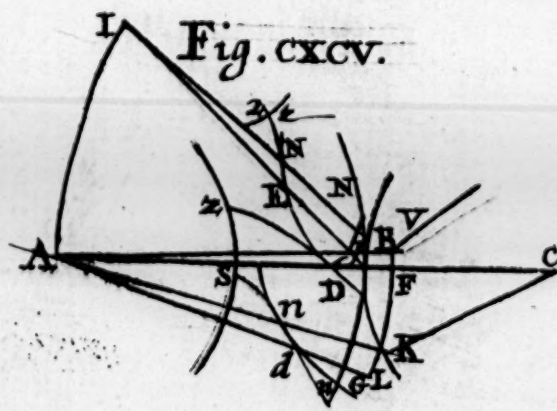
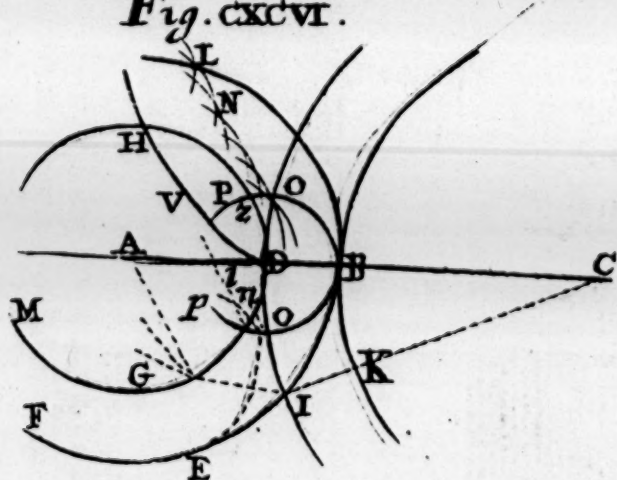


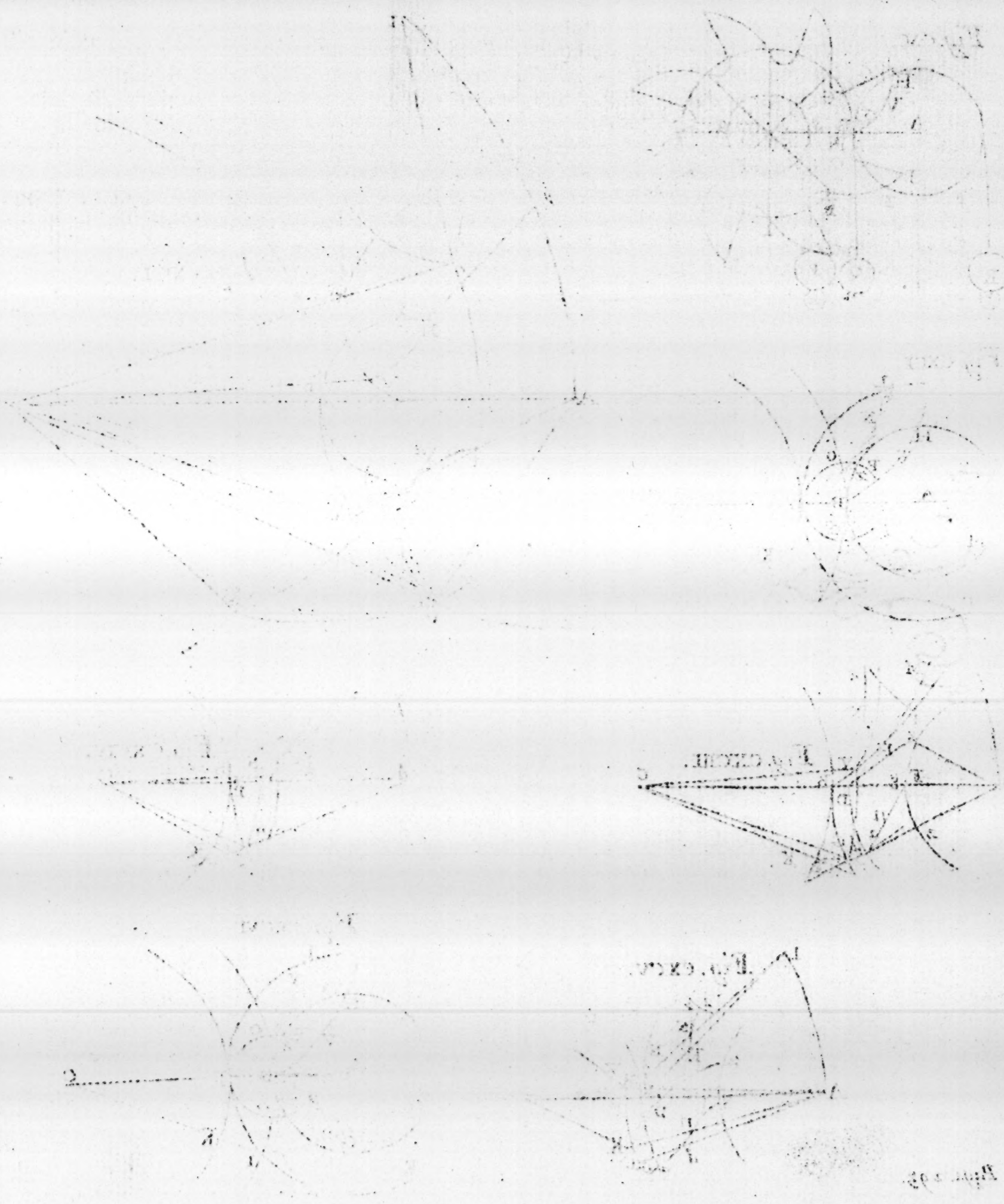
Fig. CXCV.



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'Tis evident, that this application of the little wheel cannot make any varying from what I have demonstrated of the circular Tooth in the 6th. Proposition, and that the effect of the Engin will be the same: For it matters not whether the Curve O N L rencounter or meet the circle O Z P of the little wheel, or the tooth of the same figure, since its center D will be always the same way.

P R O P O S. IX.

The Construction of an Engin to raise Water according to the precedent Form.

Fig. **L** M O I is a great Wheel made of great pieces of wood 197. **L** joined together one with another, which is posited or placed horizontally, the Axis, or Tree A B, of this Wheel is a large piece of wood which is moved by its base on a Pivot, or Spindle P, being only fastned at top with a pin of Iron to keep it always perpendicular: This Wheel is toothed, or waved, on the edge after the manner of Wheels in rencounting, or meeting, in common Clocks; and it hath but 5 Teeth, as O I, which act in passing upon the little Wheel R S, which is movable on its axis C: This Axis is fastned to the arm D C, which is likewise movable about its axis D, which is stayed firm at any union: The arm D C is join'd and fastned to the portion of the circle D E F, so that they cannot move the one without the other; on the thickness of the arch E F it must have a double flat chain H G, fastned towards the top in E, and this Chain hath two rings at the end of it, which sustains the handle of Iron which carries the Pin, or Pestle, of a drawing Pump: The Leaver, or Arm N, of this Engin passes in the Tree in B, and may be stayed if one will by the wheel to make it more firm; it must have two little Wheels, such as those I am coming to describe, which are diametrically opposite under the Wheel, and which do always act by turns one after another; for by this disposition of the little wheels when one appears in the bottom, or hollow of the wave, the other appears on the top: But the Wheel turning from O to I, the little wheel descends in the rencounter to the part O Q of the wave, and amounts again in the other, we must consider

consider but the part O Q of the wave, for there is but that that works for to lower the little Wheel which raises the Pestle, or Sucker, of the drawing Pump, and which sustains all the weight of water; the little Wheel mounting again in the other part of the wave makes not any effort or endeavour against the Wheel, for it follows only the hollow turning, or winding of the Tooth, not being raised but by the weight of the Pestle, or Sucker, and its handle, and of the Triangle D E F, which fall again beneath by their proper weight, which we may make very near equal to that of the little wheel.

All the effort of the Wheel is made only by its weight in such manner, that if it is as heavy as the weight of the Column of water which it ought to sustain in the body of the Pump, the distance of the Leavers being compensated, 'tis evident that there will not be any considerable rubbing on the pivot P: But it must be always somewhat heavier, so that it may not go out of the Iron wherein the Pivot plays, for otherwise it will work on the two little wheels all the time, which must be avoided.

The number of Teeth of this Wheel ought to be odd, so that it may have always one of the two little Wheels opposite which work, and that the power which moves the lever N, may act always equally, and not by jumps or skips, as it commonly happens in those Engines which have not one or two wheels. 'Tis in this that the principle direction of the construction of Teeth, and the position of small wheels consists: For which, that we may always keep to the rule in the form of the Teeth, we must have respect to the proportions of the height and length of the Teeth with the diameter of the wheel.

We must observe that 'tis not possible that the face of the Teeth, or of the waves of the wheel, should work in every place on the little wheel at equal distances from the Axis of the wheel, because the motion of the wheel is circular and horizontal, and that of the little wheel is vertical or perpendicular; for it happens that when the Teeth rencounter the little wheel in their lower part, and from their point, if the Axis-tree of the little wheel is equally removed from the Axis of the wheel, it will be nearer when the little wheel is towards the moiety of its descent, which will be easily known in the plane; this difference of removing will cause a little fretting or
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wearing of the face of the Tooth with the little wheel : But these are such faults which are impossible to be wholly avoided in Engins, and we ought to respect those which have the least, or the least considerable, for the most perfect.

For the construction of the Teeth of the great wheel of this Engin, we ought to consider them as if they were in the same plane as those of the little wheel, and when we have determin'd the figure, we apply it on the wheel to the place where it rencounters, or meets the little wheel, serving as a profile or fit size cut from the figure of the Tooth.

Fig. 198. Having determined the center D of motion of the arm D C of the little wheel R S, and the size D C of the arm, from the center D, and by the Radius D C describe the circle C E, on which draw the line A B C touching in C; on the line B A for a base, and C E for the generating circle describe the Cycloid C V V, and through all its points V V as centers describe the circles N equal to those of the little wheel; I say, that the crooked or curve line S N N which touches all those circles will be the figure of the Wave.

If we imagin that the right line B A moves from B towards A on the same with the Cycloid C V V which is fastned to it, 'tis evident that every point B of the line B A will have so much of the way as the point C will have about the center D, being moved by the Cycloid V V: For if the point C of the line B A is transported in T through the space C T, the Cycloid C V will be placed in T E, and the point C will be arrived at E, on the arch of the circle C E: But by the generation of the Cycloid, the arch C E is equal in length to the right line C T, then two equal powers one of which moves the line C T on the same, and the other moves the point C about the center D, will make an Equilibrium every where, for we ought to consider the right line B A as the circumference of a circle whose center is infinite or endless.

But now if instead of the point C of the Radius D C, we apply the little circular wheel R S, whose center is in C, 'tis plain by the construction of the curve S N N that it will have the same effect on the center C of the little wheel in rencountering its circumference, as if the Cycloid C V V should rencounter only the point C: For the center C being put or placed in E, the point N of the curve S N N will be placed in *n*, so that E *n* will be a shorter distance from the point E of the curve.

In the construction of the Teeth of this Engin, one serves not all the curve SNN form'd on the whole Cycloid, but only on one part, and that which you please, for otherwise it would happen that the waves would be too great. We may then take for Example in *Fig. 31.* the middle part NX of the whole curve $SNXF$, which is formed on the half Cycloid CN ; so the bottom of the wave will be formed by the circle of the little wheel in the position NZP , and its point will be in the point X ; we may give very near the same figure to the part of the Wave which mounts up again and works not, to the intent that the little Wheel may roul away more easily in remounting within the bottom.

Fig. 199. We must note, that when the little Wheel is come to the end X of the Wave, the center M of the little Wheel is not so far as it may be from the point X , that is to say, that the line MX is not perpendicular to BC : But as the point X describes a line parallel to BC , it works only on the circumference of the little Wheel, until that the point M is come within the line MX , perpendicular to BC ; the center M of the little Wheel will describe then in that place a small arch of a circle equal to those of the little Wheel, and it will happen that the point X of the wave will be blunted or dulled a little in the succession of the work, which will not happen if one serves for all the curve NXF ; for the wave will not be one point from its extream F , as in the point X , because that the Touchant of the curve in F is Parallel to BC , and the Touchant in X is inclined to the same line BC : 'Tis evident, that the work of the point X will only endure so much more time as the little Wheel is more great; for the arch which the point M describes, will be greater for drawing the point M , in the line drawn by X perpendicular to BC , than if the Radius of the little Wheel should be lesser: There is still one inconveniency in a great little Wheel; for it must have greater ballances on one side, and on the other under the wave, because that it moves on two points one of which is its Pivot, and the other is that of the arm and of the Portion of the circle which carries the chain, which will not be so considerable in a small Wheel: But if the little Wheel be very small, it must take away a greater portion of the curve NN , to form the wave that it may have always the same Elevation in the pestle, or rod of the Pump.

'Tis

'Tis easily seen that the chain which is fastned to the portion of the circle serves to raise the Pestle always perpendicular, which is a very good use in these sorts of Pumps: For otherwise if the handle which carries the Pestle, be only fastned to a Leaver movable about an axis as D in this Engin, it will happen that the Pestle will be drawn sometimes to one side, and sometimes to the other, and wear unequally in the body of the Pump in working, which will destroy it in a third part of the time, as I have observed in some rencounters.

P R O P O S. X.

We may likewise apply the same construction to wings, or to the Axle-tree of Mills, which have their Wheel vertical, and which are for Powder, for Paper, for Fulling, for Forging, &c. or it may raise Pestles, very near as you see represented in this figure.

Fig. I Shall here represent only two of these Pestles, but we
200. I may put as many as we please, or as many as the mover of the Wheel can make to go; you must always put two wings opposite, as A B and C D, to work on each Pestle, to the end that when one of these Wings as B having quitted the little Wheel E from the arm of the Pestle, and that it is fallen, then immediately the other Wing A, which is opposite to B, begins to relieve it.

We may also observe that if we have two Pestles, it behoves that the wings which belong to each one, will be applied one after another, to the axis of the Wheel, as we see here, where the Axis is to 4 Panes, because that it hath four wings and two Pestles, and where the wings A and B are applied to the two opposite faces of the axis, and the two other wings C and D, which belong to the other Pestle are applied to the two other opposite faces of the same Axis: If we would then have three Pestles and six wings, we must cut the Axis, or Tree, into 6 panes, or sides, and if we would have four, we must cut it into 8 sides, unless we apply two Pestles on the same face, and then there needs but half of the faces to the tree.

But it must be observed that we do not place the wings together, which are applied to the same face, but to mingle them with the others, that so the Endeavour, or effect, may distribute it self equally on the Axis, or tree, that is to say, that the raised Pestles should not be together.

I do not represent in this figure but one of the kinds of making the motion equal, which is by giving a crooked figure to the wings which are fastned to the Axis of the Wheel, and by placing the little Wheels to the end of the arm of the Pestles, although there be yet another, in making the arms of the Pestles of a curved or crooked figure, and in applying the little Wheels to the end of the right wings of the Axis of the Wheel: But I will explain these two kinds in the construction of the Curves or Crooks.

I have not given here the conjunction of this Engin, nor the manner of strengthning all the pieces, 'tis sufficient for him that regards the Mechanicks to shew the disposition, the rest belongs to the Art of Carpentry.

The first kind. Fig. 201.

The first kind of applying the Curve to this Engin is that which is represented in the precedent Figure; let the point C be the Center of the Axis of the great Wheel, and CA the distance from the Center to the handle of the Pestles, on the right line CA having determind the point B, which is the extreame A B, of the arm of the Pestle, and which is the Center of the little wheel which we apply to the end or extreame of the arm; and from the center C, and by the Radius CB, having described the circle BD, make the *Epicycloid* BVV on the circle BD for the Base, the generating circle having its center at an infinite distance, that is to say, that the circumference of this circle is a right line, and that the *Epicycloid* BVV is the last of all, which is also the Curve line described by the rolling of the circle, as is noted before.

Then from all the points V of this *Epicycloid*, having described the circles N, equal to the circle EF of the little Wheel, the Curve ENN which touches all these circles will be the fashion or form of the arm of the tree, or axis of the Wheel.

Following the same method of demonstration, that I have observed before, it is evident that in whatsoever Position the

arm.

arm E N N of the axis, shall be in turning about its axis C, it will have always equality of motion between the center of the little Wheel which rises perpendicular, and the point B which it moves about from the center C: For if the center of the little Wheel B is transposed in H, following the line B H parallel to A G and perpendicular to A C, through the Curve E N N transported in L n n about from the centre C, it is evident that the point H, will be found on the *Epicycloid* B V V, removed in K H, with the Curve E N N removed in L n n: For the shortest distance from the point H to the Curve L n n, will be equal to the Radius of the little Wheel E F: But by the Formation of the *Epicycloid* B V or K H, the arch B K of its Base, will be equal to the arch of its generating circle, which is here the right line B H, which represents also the way from the center B of the little Wheel, while the same point B describes the arch B K: But the ways B K and B H being equal, and the Powers equal applied in B, of which the one acts to the end B of the Leaver C B, and the other to the end B of the infinite Leaver B A, or determin'd to what distance you please in A, for the length of the Leavers ought not to be consider'd when the Powers are directly opposite the one to the other, it will follow that you will have on every side an Equilibrium between the two equal Powers.

We do not consider here the rubbing or wearing of the handle of the Pestle throughout the hollowing of the wood it runs in, for to make it raise perpendicular, for we suppose that the Bodies are exceeding smooth, and that the rubbing or wearing hinder not in any manner the motion.

The Second kind. Fig. 202.

In the Second manner it must be that the arm of the Pestle is of a curve figure, and that the little Wheel is applied to the end of the arm of the Tree, or Axis of the Wheel.

The figure of this arm, or wing, is not determined: Since there is no regard, but to the length from the axis of the tree, even to the centre of the little Wheel, which works on the arm of the Bar, or Pestle; it behoves only to take heed that the Figure as C K D, which we give to this arm, or wing, hinder not the motion of the arm of the Pestle.

Let then, as before, the handle of the Pestle be $A G$, and the center of the Axis C , having drawn the Perpendicular $C A$ on $A G$, mark on $A C$ the Radius $A B$ of the little Wheel, and by the point B draw the line $B E$ parallel to $A G$, which will be the Base of the Cycloid $B V V$, whose generating circle will have the length $C B$ for its Radius: If from all the points V of this Cycloid, we describe the circles N equal to those of the little wheel, the Curve line $N N$ which touches all these circles will be the Figure of the crooked arm which we ought to apply to the handle of the Pestle.

'Tis evident by the generation of the cycloid, that if we move the cycloid $B V$ on its base $B E$, in what place soever 'tis placed, as in $E D$, the end B of the Radius $C B$ being removed by the cycloid in D , the arch $B D$ will be equal in length to the right line $B E$ of the base; but if in stead of the cycloid we use the curve $N N$, we see clearly, as in the precedent propositions, that this curve will make the same way to the point B , from the end of the Radius $C B$, in rencountering the little wheel $A F$, whose center is in B ; for the curve $n n$ which rencounters the little wheel, cannot advance its center, or make it move forward, but from the distance of that center to the cycloid, which is that from the Radius of the little wheel: But as these motions, or movements, are every where equal, there will be an Equilibrium between the two equal powers applied, as in the precedent example, which does not require any long explication after that which I have said of other Engins.

There is only in this case one difficulty for the construction of this Engin; for as it is, that the little wheel lays hold on the arm of the Pestle below, if the arm of the Axis, or Axle-tree, which carries the little wheel, be right or streight, it rencounters the curve before that the little wheel touches it; we must then bend or make crooked the arm a little, as the line $H K D$ shews; to the end that the little wheel begin to rencounter the curve $F N N$, when its center B is in the line $C A$: But as it is difficult to make these sorts of curves $H K D$, unless it be of Iron, we may also make to serve an arm every way right or streight which shall bear or carry the center D of the little wheel, but then the arm must be double, and the little wheel must be applied between two to the end, for the crooked.

crooked arm of the pestle F N N will pass between these two streight pieces which bear the little wheel.

We must observe here, as in all the other Engins, that the little wheel be small; for when the crooked arm which it rencounter or meets, ceases to work by a perpendicular line drawn from the center of the little wheel to the curve, it ought to cease in the Rencounter, or discontinue to meet it, which is not possible, because it serves but one part of the Curve: It happens then that the extream of the arm works still by its point on the little wheel, in making it turn on its center until it be entirely got away, and in the motion, the *Equilibrium* between the powers is not found any more, which is a defect in the Engin, which we must avoid and lessen by making the little wheel of a small Diameter.

P R O P O S. XI.

Of the Length and Disposition of the Teeth of Wheels.

Fig. 203. **I** Have already demonstrated, that it is not necessary that the teeth be equally distributed on the wheel, when they are of a regular figure to make them act equally one with tother; for if we have but one, it will be as if we had more which work, the powers applied to these wheels act always in the same reason or proportion, the one with respect to the other. But we must take heed that when one tooth as O N L, which is cut as L, ceases to work on the other Tooth P Z, that is to say, when the Touchant in L of the curve O N L, is also Touchant in the same point L of the curve P Z of the other tooth, there must be two other already of the two wheels which work together; for otherwise the extream L of the tooth N L rencountring still only by the point L, the curve P Z will not be moved as before, and the motions of the two wheels will not be equal between themselves: It is not possible in this case to rectify the motion in seeking the figure which rightly agrees with the Teeth of the wheel A, to make the point L work equally on the Tooth P Z; for the point L rencounters the Tooth P Z, in the same points where it already is rencountred by the curve N L. But when another tooth begins to work, or hath workt already, when the point L ceases to work regularly on the Tooth P Z, the point L ceases also

to rencounter the tooth P Z; but because the wheel to which 'tis fastned is moved always with an equal motion by the rencounter, or meeting of the other teeth of the wheel C, which makes it go further than the point L alone should do, for this wheel A will have always the same way, as if the Tooth P Z should be rencountred, or met, by the curve ONL prolonged, or lengthned; then the point L will remove aside from the tooth P Z, and they will work together only so much as they can do it regularly, which is a great advantage to an Engin.

We ought also to take heed that the Teeth of one wheel rencounter not those of the other wheel above the points, where they ought to begin to work, that is to say, towards G, above the line A C, which joins the centers of the wheels for the reason of rubbing or wearing, as I have already taken notice of before, for the rubings which are made of bodies, which go one on another are always very great, and on the contrary those that are made by slipping, are very inconsiderable, wherefore we ought to dispose the Teeth in such manner, that they trouble not, nor hinder one another before they begin to work, and that there be a convenient length and depth given them, for power to disengage themselves easily the one from the other.

We may yet note, as I have done, that the part of the tooth which works not, may have what figure you please, and that we ought only to seek those which gives it most constancy or steadfastness, and which may serve for disengagement. Nevertheless it is left to be done as workmen use in their common discoveries of giving to teeth the same figure of both sides, as well to inure to make these teeth all equal, as to serve also to the motion of the Wheels, when we would make them turn in a sence contrary to that which is necessary for the use of the Engin; which we are obliged to, oft-times in the building and taking of them too pieces.

PROPOS.

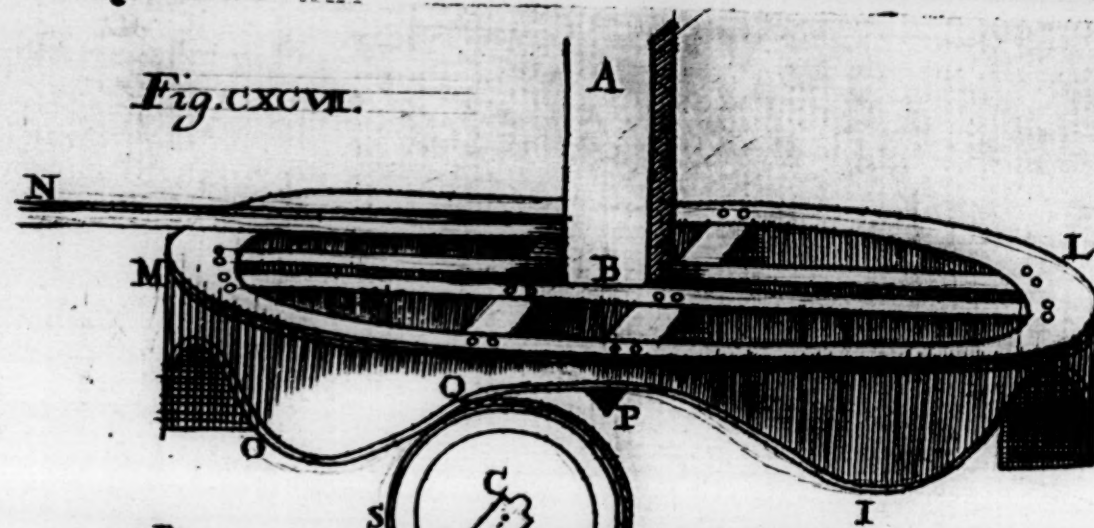


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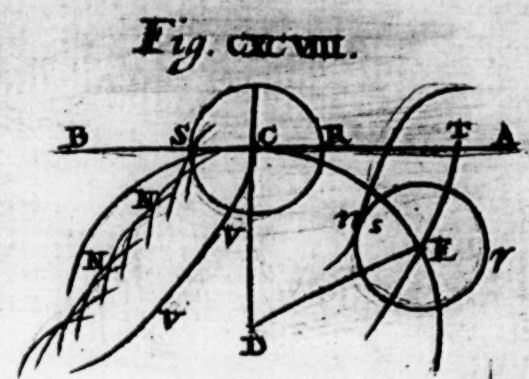


Fig. CXCVII.

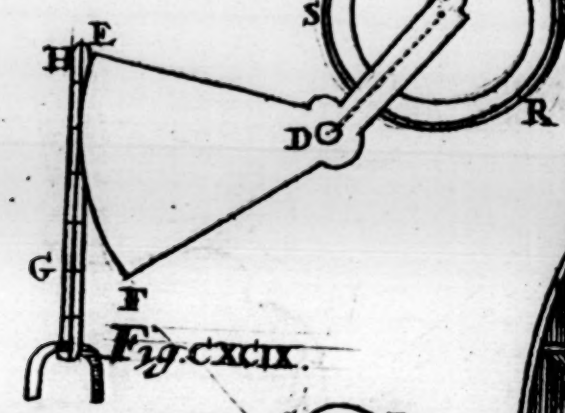


Fig. CXCIX.

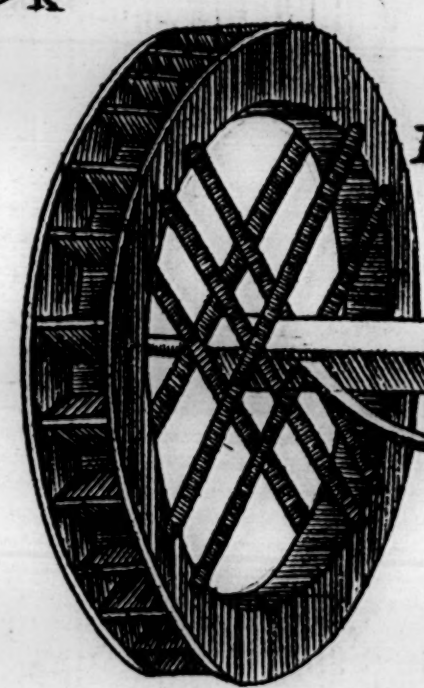
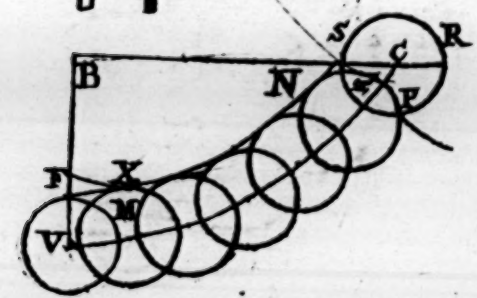


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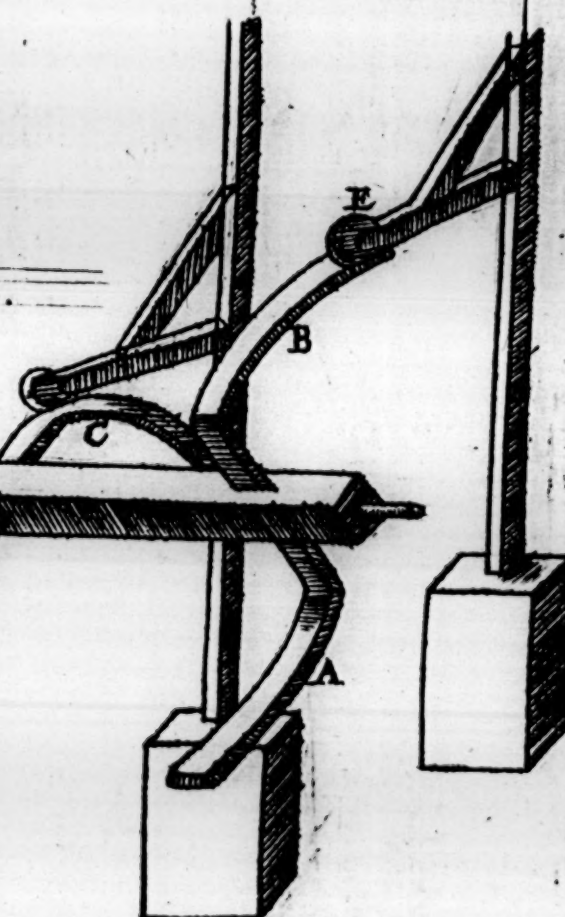


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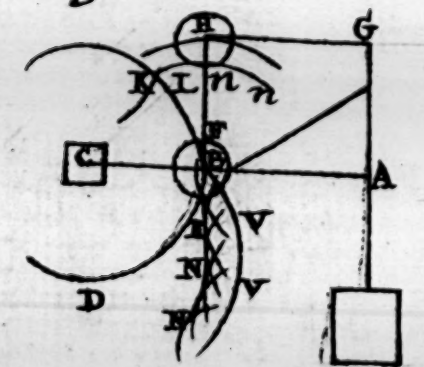


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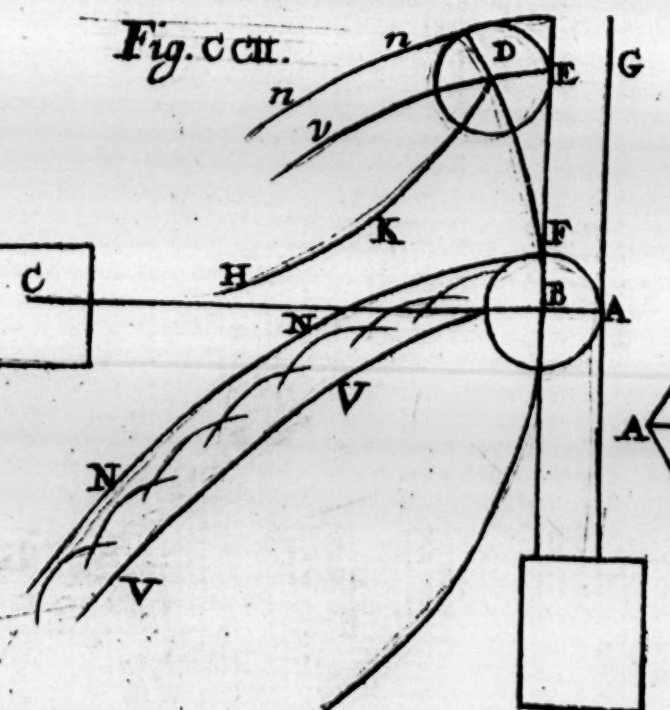
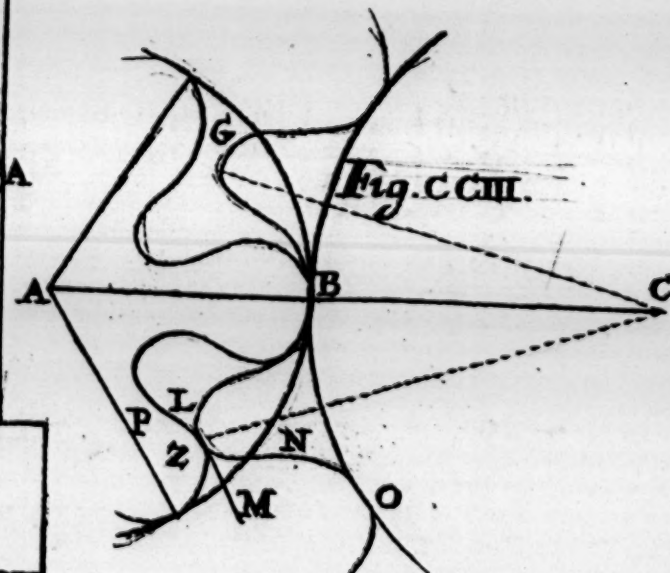
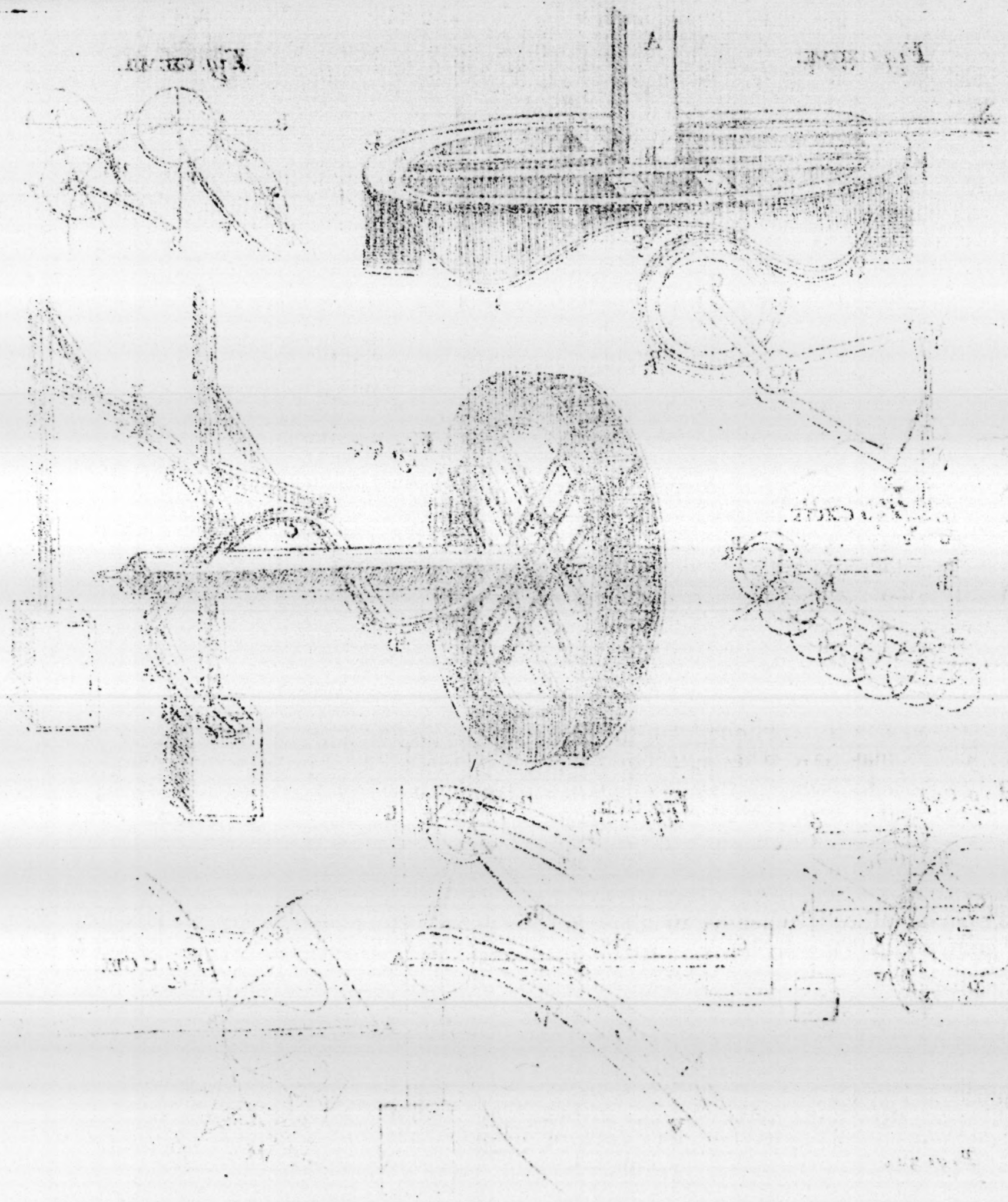


Fig. CCIII.





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P R O P O S. XII.

To make an Engin which serves to move several Sawes for the sawing of Stones. Fig. 204.

A B, is a Frame, or Shas, in manner of a square figure, which may move easily from C towards B, and from B towards C, being kept within a kind of hollow gutter of wood, in which it moves on little wheels which are fastned to a piece beneath : In this Frame you have two pieces of wood joined at right angles in G and in F, with the pieces of the Frame A M, C B, and which are detained by two bonds or braces from the sides of the Frame, there must be also in the two other angles of the frame two bonds or braces in D and in E, which serve to strengthen it.

In the middle of this Frame there must be a Triangle of wood H I K, which is sustained in the middle on a large piece of Timber, or Axle-tree L, on which it is well stayed, and when this large piece of Timber, or Axle-tree, turns, the angles of the Triangle, which are furnisht with small little wheels in I K H, come to rencounter the pieces of wood G F one after another, making the frame A B to move from one side to the other in the hollow gutter, by forcing it in G, and afterwards in F.

Towards the ends of the pieces of wood A M, C B, there must be two rods of Iron, as M B, which must be well fastned, which must bear two hands of iron N O, which may run along these rods of Iron, where they are engaged at one end, and on the other they are well fastned to one of the arms of the saw P. Whence it appears, that when the Frame is moved, it makes the saws P to move which are on the two sides of the frame ; and according as the saw works, the hands descend by running along the rod M B.

According to the force of the power which turns the axle-tree L, we may apply many Triangles, as H I K, which will make to move so many Frames, as A B, which makes to go, twice as many Saws.

The little wheels which are applied to the angles of the Triangle, and which facillitate the motion of the frame, are of great use, because they take away the rubbing which would be

be made against the pieces G F, if there were none but the angles of the Triangle which hit against them. But although these little wheels are applied to the angles, the motion is nevertheless unequal; and for to make it equal, it behoveth that the faces of the pieces G F which are rencountred, or hit against by the little Wheels, must be formed in a crooked line, which is demonstrated and explain'd all along before in the Treatise of *Epicycloids*.

Fig. 205. How to make the bending of the face of the pieces G F; from the centre L, and with the radius L I, equal to the distance which is between the axis of the tree L of the Engin, and the centre of the little wheel, having described the circle I F, draw a part of the Cycloid I S on the right line I Q, which touches the circle in I, and which will be the base of the Cycloid, the circle I F being the generator, and the beginning of the Cycloid being in I; then on all the points of the Cycloid, as a centre, describe the circles R which must be equal to the little wheel, and you may draw the line R R, which will touch all the circles towards the convexity of the Cycloid. The line R R will be the bending of the face of the pieces G F: We may prolong the line R R towards V, adding to it a part of the right line, even to the place where it is fastned in the piece A M of the frame: You must observe, that the little wheel in working ought to apply it self in the curve or bending R R, in the same manner that the circles R R are placed, that is to say, that the pieces G F ought to be a little more bending towards the middle of the Frame.

P R O P O S. XIII.

To change the direction of Motions, or Movements, by the means of toothed Wheels. Fig. 206.

L Et the wheel be A B which turns on a vertical Tampin C, whose teeth are placed perpendicularly on the plane of the Wheel.

If we would move this Wheel A B Horizontally, by means of the arm D E, and that its teeth rencounter, and enter in the Spindles of the Lantern G F, which moves on its Horizontal Tampin

Tampin M N, it is evident that the Horizontal movement of the Power applied to the arm D E will be changed into a vertical movement or motion about the Tampin, or the Axle-tree M N, of the Lantern.

Also by means of an Horizontal motion we may raise the weight P, whose Chord is wound about the Roll O, which hath its axle-tree common with that of the Lantern F G.

But if instead of the Lantern F G, whose spindles are parallel to its axle-tree, we would make another, as H I, whose Spindles are inclined to the axle-tree K L, in what angle we please; it is evident, that the horizontal motion of the power applied to the arm of the wheel, will be changed into a motion inclined to it, in what angle one will about the axle-tree K L.

Only note, that the Spindles of the Lantern H I, which rencounter the teeth of the wheel A B, must find themselves places horizontally in the rencounter, to the end, that they may be applied in the same manner, as if this Lantern were like to the other G F.

P R O P O S. XIII.

Fig. 207.

The description of a Wind-mill, together with the Computation of the force of the Wind on its sails.

They are commonly of two sorts, but they differ not but in this, that in the one the whole body of the mill turns on a Tampin, to expose the sails to the wind; in the other, the body is of stone, and none but the upper part turns to expose the sails to the wind. In these the Lantern and the stones ought to be placed in the middle of the Tower, that the teeth of the Wheel in all their different Positions may rencounter always equally the Spindles of the Lantern.

A B is the great Axle-tree, at whose end the Sails are fastned, and which serves for an axle-tree to the Wheel C D. The teeth of the Wheel C D enter into the Spindles of the Lantern E F, whose Axle-tree G H N is vertical, and which being stayed by the upper stone I K, makes it turn on that beneath L M, which is immovable.

So that the vertical motion of the Sails, and of the Wheel is converted into the Horizontal motion of the stones.

The Wheel hath commonly 48 Teeth, and the Lantern 10 Spindles, so that each turning round of the Wheel, or of the sails, causes near 5 turnings round of the stones to be made; whence you may observe, that perhaps the stones make not the whole, or more than one turning round, in one Second of time, and by consequence the sails will also make one turning about in 5 seconds: Therefore if the wind be too violent, we abate one part of the sails to reduce them from this swiftness.

It is not likely that the ordinary manner of using the force of wind, to turn the stones of mills is the most advantageous that is possible to be found, which is that which hath obliged many active workmen to seek after, other sorts of Mills to the wind, and above all the Horizontal, to the end that the sails may be exposed directly to the wind, and profit by all its force; but all these sorts of inventions have not prospered. We may perhaps believe that the Wind-mills, such as we have seen were not made at first sight in the perfection that they are at present, but that the continual use which is made of them, hath made many defaults to be seen, which one amends afterwards.

Behold the Computation of the force of wind against the sails of a mill, according to the inquiry which was made by Mr. Mariot, in his book of the *Motion of Waters*.

Fig. 208. A B represents in this Figure the Axis or Axle-tree of a turned Cylinder, and the Rule G H a cross at right angles: And I L is another rule, placed perpendicularly on the first G H, and stayed also in the Cylinder. M N O P is a small thin table, even as the precedent Rules, which is likewise placed perpendicularly on the Axis A B, and Bias so, that it makes with it an angle of 45 degrees, and with respect to the Rule G H.

If we suppose now that one Cast of water beat directly against the Rule I L, towards the point Q, and that it turns the Cylinder according to the order of the letters *a b c d*, but that the weight R placed towards the end H, of the Rule G H, makes an Equilibrium with the force of the cast of water Q, that is to say, that it hinders the Cylinder from turning; It is certain, that if the same cast of water beat against the Table M O, also in the point S, which being also so far removed from the Axis of the Cylinder, as the point Q, and

and that the direction of this Cast be perpendicular to the Table, it cannot support the weight R, because that its direction will not be according to the motion of the Rule I L, which is in a plane perpendicular to the Axis A B; but it cannot at that time support that weight which shall be to the weight R, as the side of a Square to its Diagonal.

And if the same Cast is parallel to the Axis A B, and that it hit against the Table M O in the same point S, it must still diminish in its attempt in the same Proportion of the side to the diagonal of a square, because that this Cast falls obliquely against the Table under an angle of 45 degrees.

It is then evident, that this double reason of diminution ought to reduce the weight R to its moyety, or half part.

Now the wind which beats against the sails of a Windmil, beats, or blows, obliquely, and if it rencounters each sail under an angle of 45 degrees, it follows then from what hath been said, that it will not have but a moyety of the force which it would have, if it rencountred directly, and if the sail, be placed on the Axle-tree, as the Rule I L on the Axis A B. If we suppose then that the whole force of the wind be as 80, it will be reduced to 40 for these two causes.

But there is yet one cause of Diminution of the force which comes from the same obliquity, for it will have a less breadth of wind which rencounters the surface of the sail, than if it had been directly opposite, and this diminution will be still in the same reason, or proportion, of the side of a Square to its diagonal, which will in the end reduce the whole force of the wind measured by 80, to $28\frac{1}{4}$.

But if the obliquity of the sail is less than 45 degrees, that is to say, if it is more exposed to the wind, whereof we suppose the direction parallel to the axis A B, and that the angle be of 60 degrees on one side, and 30 on the opposite, then the first cause of diminution reduces the force from 80 to the moyety 40, but the two others unlike, for they reduce not but from 40 to 31 very nigh; which gives us to understand, that it is better that the sails of windmills have this obliquity than that of 45 degrees.

By these suppositions of Mr. Mariots, if the swiftness of an indifferent wind is of 24 feet through each second of time, as one may know by experience; one wing or sail directly opposite to the wind, and which hath 144 feet in its superficies

will sustain a weight of 210 pounds, if the distance from the support, or the centre of motion, as the Axis A B in the precedent Cylinder, even to the place as R, where the weight is placed, is of 12 feet from the same, as the distance from the centre of the sail.

But if the sail have only 6 feet in breadth, and 24 feet in length, it will have the same superficies of 144 feet, and its Centre will be also 12 feet from the Axis; wherefore it will sustain as yet the 210 pounds, having 12 feet of distance from the Axis: But if the distance from the axis to the Centre of the sail is of 15 feet, it will sustain 262 pounds and $\frac{1}{2}$.

But through these three causes of diminution they suppose the angle of the sails of 60 degrees, with the Tree, or Axis, where they are fastned; the force of the wind reduces it self to sustains 101 pounds and $\frac{3}{4}$, having 15 feet of distance from the Axis: And because there are four sails, the force of the wind will sustain 407 pounds at the distance of 15 feet from the Axis of the sails.

But the femidiameter of the wheel being supposed of four feet, if we make it as 4 to 15, so 407 to 1526, this will be the number of the pounds which measures the force of the wind against the Spindles of the Lantern, in the supposition that it makes 24 feet in one second; there is no regard of the rubbing, or wearing, in all these Calculations.

In the horizontal Mills you cannot have about but one sail, against which the Wind acts directly, and it must be made of an extraordinary greatness, for to cause the same effect as the 4 vertical sails of ordinary Mills, as 'tis easy to compute by the precedent Suppositions.

P R O P O S. XIV. Fig. 209.

Of Wheels, and of Lanterns, with their Elbows, or crooked Axes, for the moving the Suckers of Pumps.

IF the power turns the wheel vertically, we must only bend the ends of its Axis, as you see here in the figure G H. But if the motion of the power be horizontal, as if it be applied to the arm C D of an horizontal wheel A B, you must adjust the Lanterns E F, so that their Spindles enter in to the

the teeth of wheel, and that their crooked axes may work the effect that we desire.

In each crook of the Axis your may put a kind of little ring I, which is fastned to the end of the Iron of the sucker K, so that in the motion of the Lantern, the crooks of the Axes raise them and let them fall alternatively, or by turns one after another, these raise and depress the Pestles, or Irons, to which the Suckers are fastned in the body of the pump; this also makes it give one stroke of the Iron to each turn of the Lanterns.

We may make the diameter of these Lanterns a fifth part very nigh of that of the great wheel, to the end, that for each going round of the great wheel, the Lanterns may make five. But however commodious this Proportion is, we will not make a Rule, because it must have regard to the swiftness of the power which may be too great for this proportion, and which will move the Rods, or Pestles, too nimbly.

P R O P O S. XV.

In toothed Wheels the number of Teeth must not contain exactly so many times the Teeth of the Pinions, or Spindles of the Lanterns to which they are applied.

THIS Rule concerns only the execution, and we ought to have regard to make it so, that the teeth of the wheels do not always rencounter the same teeth of the Pinions, for when they rencounter, or meet different ones, they grow perfect in rubbing and in using themselves one against the other, and by degrees they make very nigh the figure which behoves them, for to act equally in their different rencountes, and in the different lengths from their Axes, which is explained in the Treatise of *Epicycloids* before.

It behoves to practice this Rule exactly, that the number of the teeth of the Wheels, and of the Pinions, must be Primes between themselves, that is to say, that they do not admit of any other common measure than Unity, and so the same tooth of the little Wheel, or Pinion, rencounters not the same tooth of the great Wheel, but after that the little one hath made so many revolutions, or turns, as there are teeth in the great wheel.

But

But because there is but little difficulty to make one division of two prime numbers, we may make the number of teeth of the great Wheel; for example, of 48 or 60, and those of the Pinions of 6 or 8, and in the Mills, the great Wheel of 48 teeth, and the Lantern of 10 Spindles, to the end that the same teeth may meet as few times as is possible; for if the Wheel have 60, and the Pinion 6, the least numbers which keep the same proportion will be 10 and 1, wherefore the same teeth of the Pinion of 6, rencounter not them of the Wheel but after 10 revolutions; and if the great Wheel have 60, and the Pinion 8, the teeth of the Pinion rencounter not the same teeth of the Wheel, till after 15 revolutions, because that 15 and 2 are the prime Numbers between themselves, which expresse the relation of 60 and 8: Lastly, if the Wheel have 48 teeth, and the Pinion or the Lantern 10, the teeth of the Lantern rencounter not the same teeth of the Wheel but after 24 revolutions, for the numbers 24 and 5, are the two prime numbers which expresse the relation between 48 and 10, and 'tis this which makes us see that we cannot find a number of teeth which is more proper for the Wheel, and for the Lantern of Mills, for the division into 48 parts is easy, and may be done very exactly, and that of 10 is commodious, and may be reduced to 5.

P R O P O S. XVI.

Of oblique and interrupted Movements, or Motions.

Fig. 1 IF the chord D of the weight P, be wound about on the roller of the beam G, and that the chord F which ought to draw the little wheel E, by means of the pulley L, on which passes the chord F, for to go to fasten into the top of the little wheel E, passing also on another pulley I, which is fastned to the top of the little wheel E, and which is stayed at last in M towards the pulley L; 'tis evident, that when the roller turns round for to draw the chord F, it windes at the same time the chord D, which is twisted on the roll G, in a contrary sence of the chord F: But if the chord F is twisted on the roll G of 6 feet long, the weight

weight P descends at the same time from 6 feet high, and will also at the same time be raised by the motion of the little wheel throughout the hollow it runs in.

But the Chord F having been drawn the length of 6 feet, it will not make the little wheel to advance but 3 feet; for as it passes through upon the pulley I, and is stayed in M, it doth not advance the pulley I, and the little wheel E, which are fastened together, but the half of its movement, or motion.

Wherefore when the chord F is twisted on the Roll G of 6 feet long, and that the chord D is also twisted or wound about of 6 Feet in length, the little wheel E will not have made but 3 feet of its way; and by consequence the weight P will not be raised up again, but 3 feet by the motion of the little wheel E; it appears then to be descended 3 feet, which is so much as the little wheel hath made of way on the hollow groove, wherefore it descends by this means by half a right angle, or it descends so much as it advances.

Lastly, if the chord D which is fastned to the round beam, is all wound up, and that it begins to wind it self about in the same sence as the chord F, then the weight P rises again; but it rises three times as much as it advances towards L: For if the chords D and F are wound about of 6 feet on the Roll of the round beam, the weight ought also to be raised to the height of 6 feet by means of the chord D, and it ought also to be raised 3 feet by means of the little wheel E which draws it, and which passes over 3 feet, while that its chord is drawn 6 feet; then the weight will be raised 9 feet while that it runs over only 3 feet in length, which is the motion of the little wheel E.

But when the chord D is wholly wound of the round beam, or cyclinder, and that the weight begins to rise, if you make a stop to the chord F, as in R, in place which it passes at that time over the pulley I, so that the cord cannot any more turn on the pulley, the same thing will happen as if it were fastned at the top of the little wheel E, and the weight will be raised 6 feet, by the motion of its chord D, and 6 feet by the motion of the little wheel E, it will then have run over 6 feet in length hanging, while it is raised 12 feet.

Now if the parts of the Roll of the round beam on which the cords D and F are wound, are of different diameters, it will make the movements or motions, different, and in different

pro-

proportions of those which I come to explain; but it will be easy to determine them, the Diameters being given, or else, the motions being proposed, it will be easy to find the Diameters of the Roll which will serve them.

We may also by the same means make it so, that one part of the way of the weight shall be Horizontal, and the other part rise or descend perpendicularly, or obliquely, which requires no long Explanation; I shall say no more of circular motions in rising, or descending, seeing they only depend or belong to the figure of the hollow groove. There is in all these motions many little cautions to be observed, which must be left to the industry of the Artificer.

We may also make many motions different and opposite the one to the other, with one and the same motion, by the means of pulleys, referring from one to another which change the direction of the motions, which serve chiefly to make the changes of the Decorations, or Ornaments, of the two wings of Theatres; for one axis only A (*Fig. 211.*) which bears the Tambours, or Cylinders B C, of different diameters, coming to turn by means of a counter poise, or weight, makes to advance towards the middle of the scene beneath the Theatre, the false frames or shashes D, which bear or carry the Ornaments or Decorations by the means of the chords C E, B E, which are fastened to these shashes, or frames, and which are wound about on the Tambours in a contrary sense: These same shashes D advancing, and those of G retiring at the same time, whose place they take, by means of one or two chords I, which are fastened to these two shashes, which pass above the pulleys that refer from one to another H, which are those in the walls of the two sides. The motion or way of these two shashes will be more or less according to the proportion of the Tambours, or Cylinders, which bear the cords of their motion.

Prop.

P R O P O S. XVIII. Fig. 212.

How to raise a weight by an oblique motion.

L Et the weight be P which is to be raised obliquely from P to A, the Engin which serves for the movement being at the height of A.

Make a hollow groove A B composed of two pieces of wood which are only removed one from another, so much as to leave room for the chord to pass freely which sustains the weight P, and which must be placed Horizontally; the chord C D H which sustains the weight P, is stayed firmly in C towards the end B of the hollowing, and passes in the overture between the two pieces of wood of which 'tis made; it passes also above the little wheel E composed of three pieces, viz. of two little wheels, or rollers, at its ends, and of one pulley between two, on which passes the chord C D H. Towards the end A of the hollow groove there is a Cylinder, or round beam G with its arms for to draw the cord F, which is fastned to the top I of the little wheel.

'Tis easy to behold by the construction of this Engin, that when the chord I F draws the little wheel E from B towards A, the weight P raises obliquely, or a slant, from H to A, and that the elevation of the weight P will be equal to the length of the hollow groove A B.

We may also make it that the Elevation of the weight P shall be in what proportion we please with its Horizontal way; for Example, that the weight P be raised 20 feet hanging, while it passes over 60 feet Horizontally.

For this effect we may place the motion of the chord F, which draws the little wheel E from B towards A at the end B of the hollow groove with a pulley towards A.

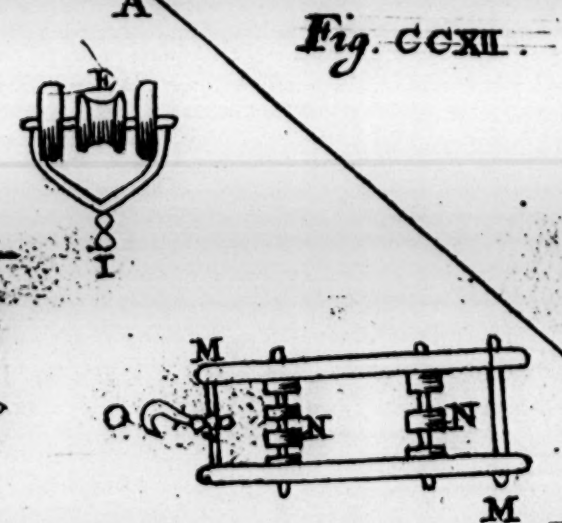
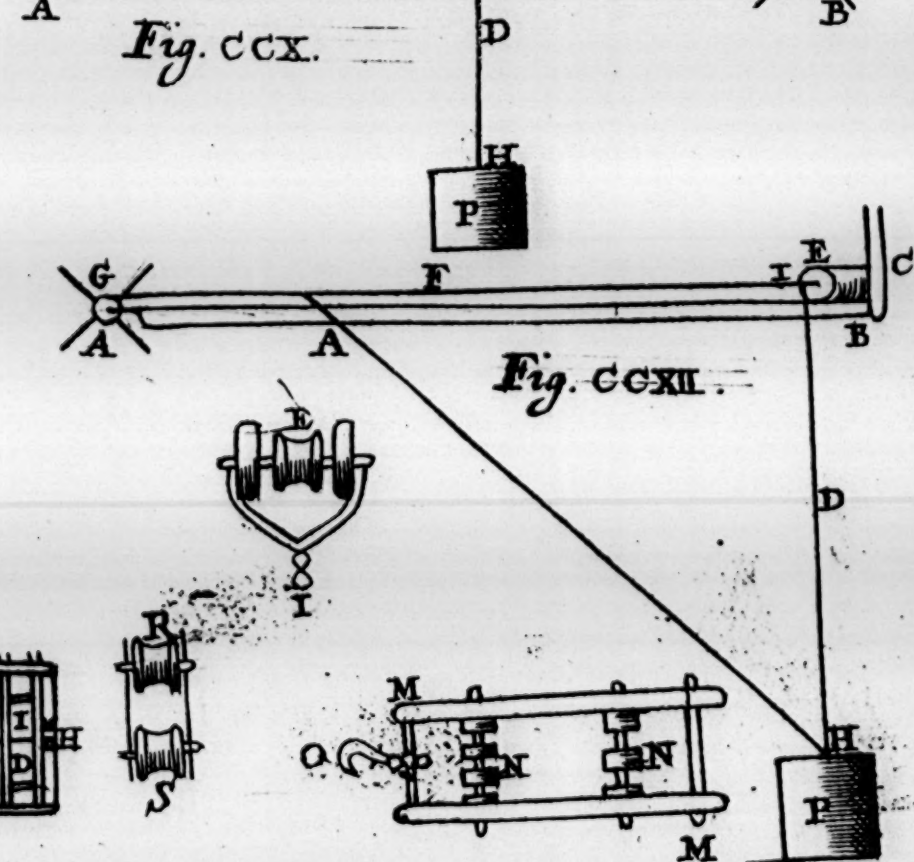
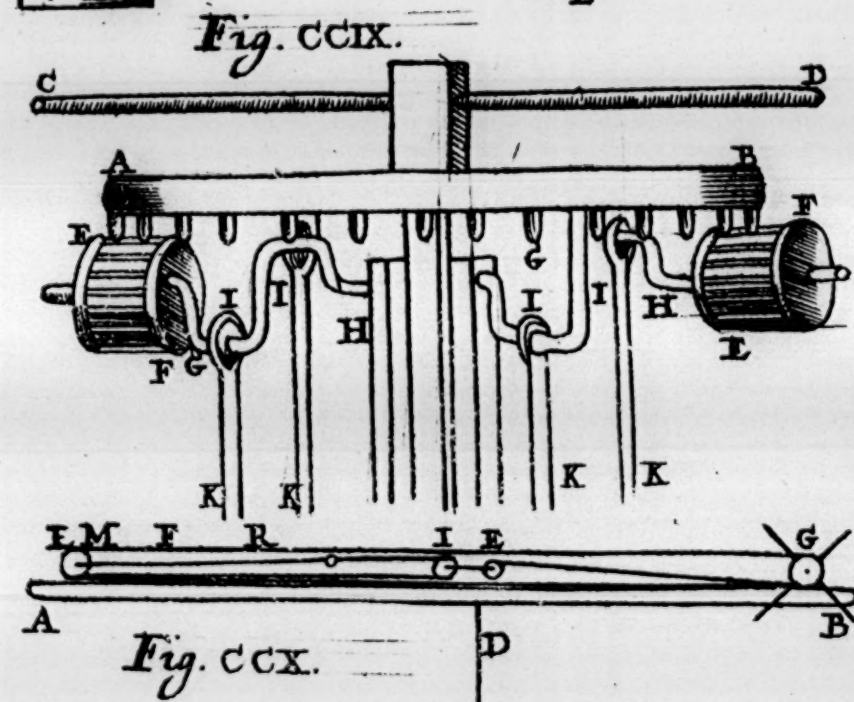
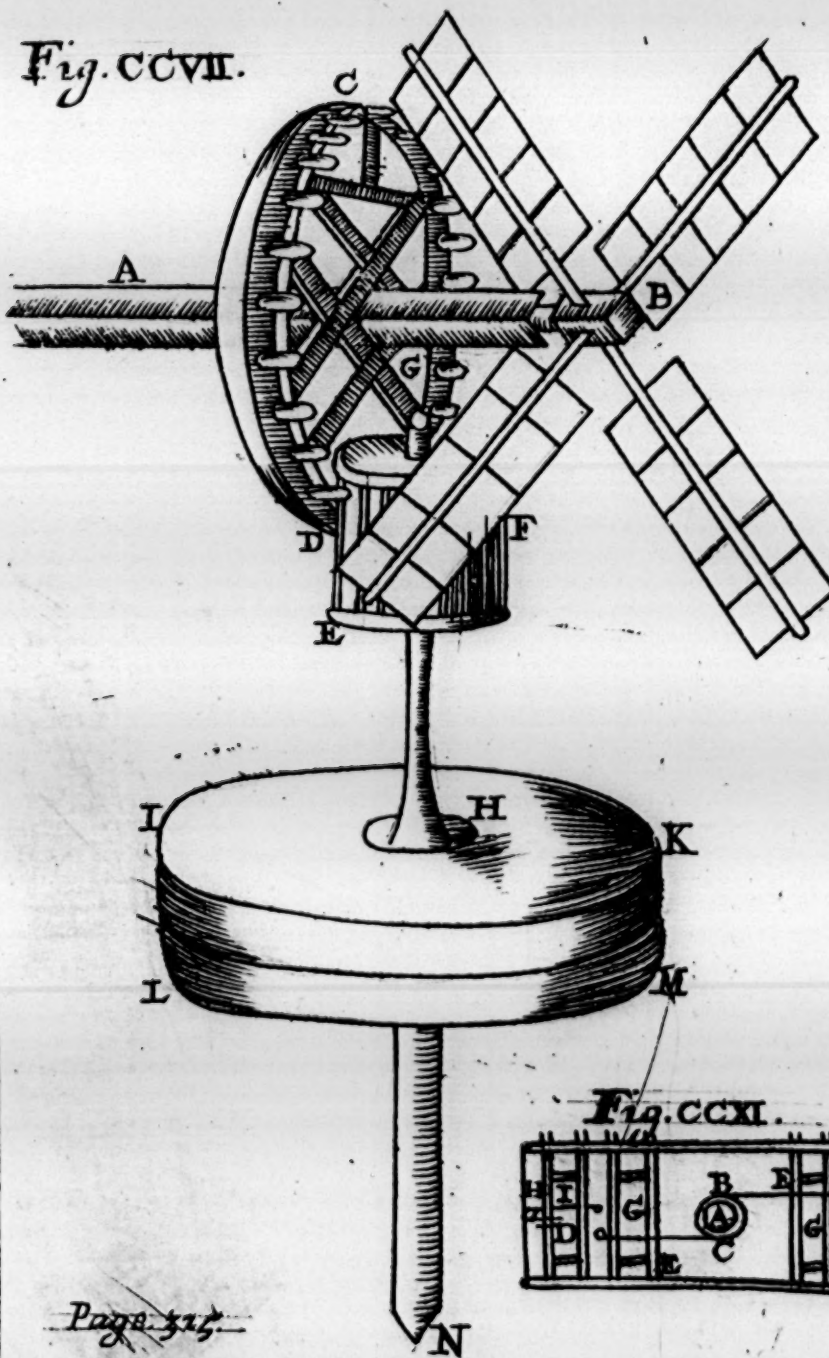
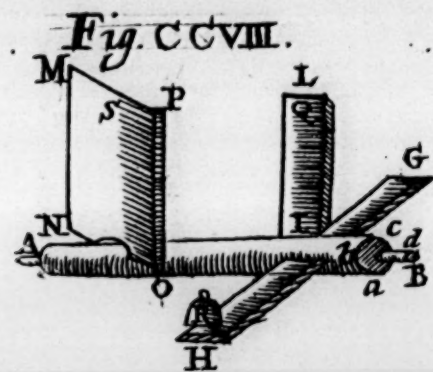
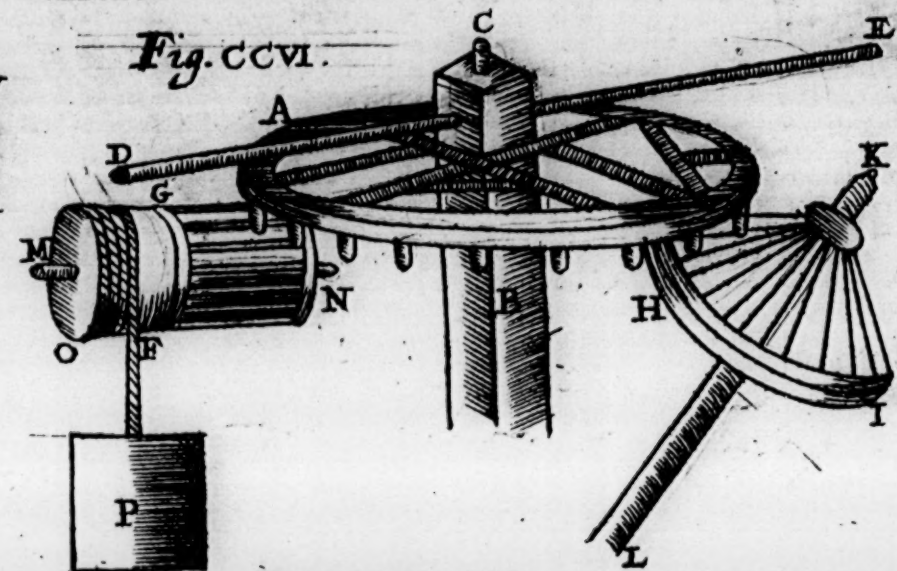
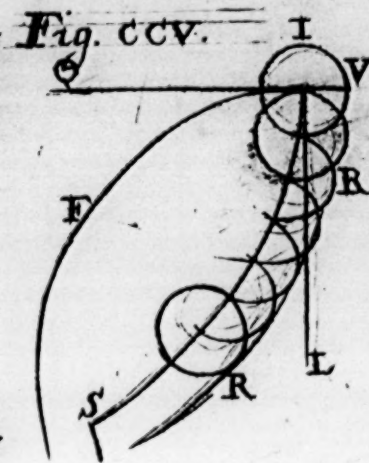
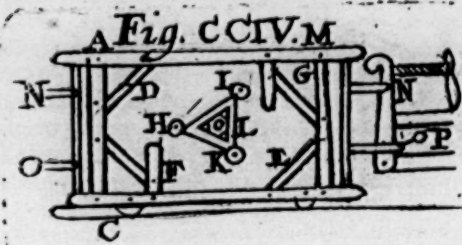
Also the round beam, or Cylinder, being placed towards B which draws the chord F, will advance the little wheel from B towards A. But then it will cause the cord C D H which sustains the weight P to be twisted on the roll of the round beam, and that it will not be fastned immoveably in the point C, as before; the place of the roll where it is twisted, must have its diameter smaller than the same where it twists the cord F, when the Cylinder makes the little wheel E to advance on the

hollow groove, and then the chord D will be twisted in a contrary sence to that of the chord F, to the end that it may wind off, as the other twists about. The proportion of the diameter of the part of the roll of the round beam where the chord F winds about; to the diameter of the other part where the cord D is twisted, or wound about, ought to be as the Horizontal way to the difference of the two ways, which is the same as 60 to 40 or as 3 to 2. For then when the chord F draws (for example) the little wheel E on the hollow groove through the space of 6 feet, that part of the roll where the chord D is twisted will have wound 4 feet; and by consequence the weight P will not be raised as yet but 2 feet, although it have run over 6 feet of Horizontal motion.

It will be the same thing for any other proportion of Elevation; only we must Note, that if we would have the weight P make a greater motion in height than in length, for example, if we would have it rise 30 feet hanging, while it runs over but 10 feet in length or Horizontally, it behoves that the diameter of the roll for the chord F be made to the diameter of that part of the roll for the chord D, as 10, which is the Horizontal way, to the difference 20 of the two ways. For if to each bout of the Cylinder the chord F make 3 feet of way, the chord D will make 9, for the circumferences of the rolls are in the same reason or proportion as their diameters; and by consequence the weight P rises 6 feet, because of the diameters of the parts of the roll, and it rises still 3 feet in the same time, which is equal to the Horizontal motion.

As to the swiftness of the motion we may give it what we please, for if the cylinder cannot draw the chords which make the motion with so much swiftness as we require, it must be done by means of a counter weight very heavy, which we may raise to an height equal to the Horizontal motion, and having fastned this counter weight to a chord wound about on the roll, where the other chords which serve to the motion are likewise twisted, but in a contrary sence, when we let loose the counter weight it will turn the roll with a great swiftness.

We commonly moderate this motion by means of a chord, which serves to make the tricker, or detainer, and which being applied against any body where it slips and retains afterwards, with the hand we may let it loose to such a proportion of swiftness as we would give to the Engin. This

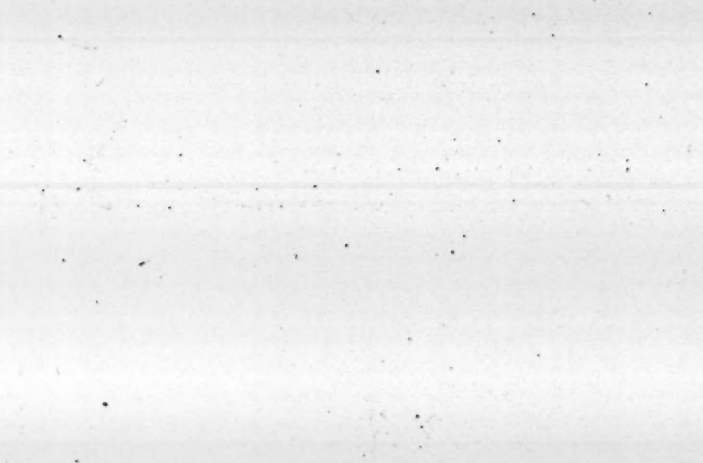




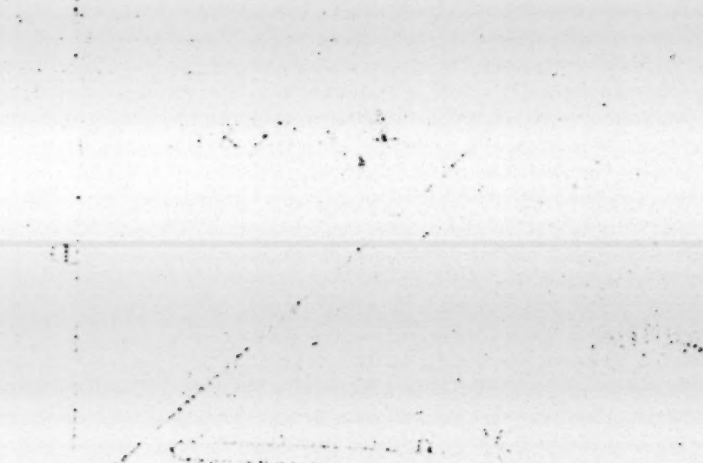
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This same tricker, or detainer, serves also to render the motion equal, which will otherwise be very unequal because of the acceleration of the counter-weight in descending.

When one chord serves it self, of many which are placed one from another for to raise the same weight, or which is the same thing, which sustains it in several places, there must be instead of the little wheel E, a shash or frame of wood, used as M M, in which there must be rolls, as N, which serve with the pulleys to pass the chords above, these rolls turn on their Axes which enter in the long pieces of the shash or frame. This shash must run along on the two pieces of the hollow groove, being drawn through the hook O where we fasten the chord which serves to its motion; but it behoves that the shash be kept on the hollow grooves that it fall not from one side to the other.

We may also instead of the hollow grooves, make one chord only to serve, being well stretched out, on which must pass a pulley, as R, which sustains another S, which serves to sustain the chord of hanging motion which the pulley R runs along in, in rouling on the chord which serves for the hollow groove.

I shall not say any thing concerning the manner of making these hollow grooves, and their detainer in different places to render them solid, because it belongs to workmen, which work in Carpentry or Joynery.

We may also make of these sorts of movements which cross themselves without trouble or confusion, for if one serves to the shash, as I have explained before, it is easy to see that the hollow grooves may be cut and interrupted in any place in a small space of 4 or 5 inches, which may serve for the passing of the chord which sustains the weight, which moves it self with a different motion from that which is borne on the hollow groove which is cut, without which the motion of the weight will be hindred; for the shash having its long pieces supported on those of the hollow groove, it may pass easily above the overture of the hollow groove.

What I have said concerning the raising of Weights, may be applied to their descent.

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ERRATAES mended thus:

Page	L.	
3	27	To the Proportion.
4	12	with.
5	30	Strike out [<i>be</i>]
7	10	Less.
11	20	Will.
11	31	Leotaudus.
12	5	A B.
12	ult	the Comma to be after [<i>before</i>]
13	36	strike out [<i>they should have</i>]
13	37	strike out [<i>they should have</i>]
14	13	Proposition IV.
27	12	Hang a thred.
28	30	<i>c</i> in like manner.
39	5	Distant.
41	15	Foremost.
53	5	Strike out [<i>in</i>]
53	20	Leaver.
53	23	then E M.
53	24	and D O.
53	26	Strike out [<i>in</i>]
55	6	add [<i>or rubbing</i>]
57	12	Axis.
	14	Axis.

Page	L.	
58	1	58 and p. 59 l. the first [59]
62	1	62 and p. 63 l. the first 63
65	9	hands.
75	12	Tube.
	19	Tube.
85	22	them.
88	25	Fig. 73.
89	9	the
90	25	Fig. 74.
91	29	will be tripled.
96	23	of.
96	24	abundant.
99	16	some things.
100	9	The whole circumference of the circle described by the wood, would be compared with the line N O.
105	27	remain.
106	2	strike out [the]
117	5	strike out [it]
124	33	strike out [the]
125	27	strike out [the]
126	9	strike out [too]
128	22	when.
129	28	to the hindmost.
130	14	strike out [be]
134	14	and a little.
137	2	Bucket M being
139	16	raised into line the 18, then
142	last	Silken.
144	25	must.
145	12	rife.
146	7	mixt.
147	34	K H.
149	2	K L; line 25 H N.
150	27	that is it.
151	23	Cabeus.
152	12	B D.
153	25	B D.
160	26	in,
163	40	Feathers.
166	last	proceeding.
170	10	of the Centre.
173	19	but only.
176	5	with a Semicylindric.
179	17	no extream end of.
182	29	by shortning the rule.
183	18	for in Fig. 129. let.
184	12	the Jags.
185	20	lightly.
185	22	a
185	31	Problem, V.

Page	L.	
186	37	consist.
187	2	wearing.
188	7	equality.
191	6	by the way:
191	17	Slowness, line 19. Clocks, Measure.
191	25	alwaies.
192	3	require greater weights; line 35, then
194	5	adapt: line 19, applied.
194	31	strike out [<i>an</i>]
196	33	wings.
197	18	in an hour.
203	32	thickness, line 30, add Fig. 142.
206	14	to be used.
207	33	prefixt.
215	8	third Minutes.
217	1	217; and so gradually in the number of Pages.
220	19	one: line 20. strike out [<i>the</i>]
221	1	221, &c. line 7, the
223	1	223, &c. gradually.
224	33	plate.
227	17	its hand: line 30 Artifices.
227	33	make a Comma after Indexes.
230	2	dividing: line 7 a Quadrate.
230	8	strike out [<i>and</i>]
231	28	they.
232	19	interval.
233	5	Wheels.
234	9	after [<i>table</i>] make a full stop.
236	28	B to C.
237	14	System. line 24. perpetually.
238	17	Leaves.
271	7	leave out [<i>left</i>]
271	12	pass.
275	10	Flexible.
276	10	strike out [<i>to</i>]
292	19	re-enter.
296	7	C V.
297	27	Axis.
298	3	Effort.
303	19	they come.
305	20	Prop. XIV.
308	15	sustain.
308	30	Prop. XV.
309	17	Prop. XVI.
310	25	Prop. XVII.
311	31	Cylinder.
311	32	in the place.